Gordon Institute of Business Science
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Exploring sustainability indicators for innovation and technology in mining

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ABSTRACT

Sustainability performance is a critical driver in the social, environmental, and financial performance of businesses that can result in cost savings, more innovation, and an increase in the value of the business brand. The expectation from society for responsible mining practices is increasing, as is the mining sectors transition into the circular economy, digitisation, artificial intelligence, and industry 4.0. This study aimed to explore the need for sustainability indicators for innovation and technology to achieve sustainability performance.

The main research question explores how sustainability indicators for innovation and technology are developed and used in the mining sector to achieve sustainability performance. In this study, a qualitative approach to conducting interviews was undertaken with professionals in the mining sector and experts in the sustainability field. The data was collected from open-ended research questions to the selected participants within the mining sector, including platinum, diamond, coal, gold, nickel, copper, and iron ore.

The key insights are concluded in a final framework of Sustainability Indicators for Innovation and Technology that shows the integration of what success looks like for sustainability indicators for innovation and technology, the critical factors to achieve this success, and the challenges and opportunities experienced.

KEYWORDS

Sustainability Indicators, Innovation and Technology, Sustainable mining, Environmental Indicators, Social Indicators, Economic Indicators, Sustainable Innovation

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 Business Administration 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.

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ABBREVIATIONS

SIs – Sustainability Indicators

I&T – Innovation and Technology

ESG – Environmental, Social and Governance

AI – Artificial Intelligence

PAR – Professional participants

EXP – Experts

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CHAPTER 1: INTRODUCTION TO THE RESEARCH PROBLEM

1.1 Research title

Exploring sustainability indicators for innovation and technology in mining

1.2 Background to the research problem – Business relevance

Environmental, social, and governance (ESG) performance is acknowledged as a critical driver in businesses' financial performance (Serafeim, 2018). Where companies are making progress on ESG initiatives, it results in cost savings, more innovation, better employee performance, and an increase in the value of the business brand (Serafeim, 2018). Göçer et al. (2018) support this view by discussing how companies are mostly motivated by economic returns, a better corporate image, and less reputational risk when considering sustainability initiatives (Göçer, Fawcett & Tuna, 2018). Revenue and net income are positively impacted when innovative solutions are pursued as less physical resources are used to produce products, or more profitable products are created, or even new businesses being formed (Nidumolu, Prahalad & Rangaswami, 2009).

The relationship between sustainability and innovation and technology has changed as businesses have recognised that innovation can lead to sustainable products and attract new market segments (Woodhead, 2011). Examples are companies such as Nike using crowd-sourcing to get customers' opinions on sustainability and customize their products to suit their customers. At the same time, Chevron has a subsidiary company called Chevron Energy Solutions (CES) that focuses on innovation through renewable energy and energy efficiency consulting (Woodhead, 2011). Various other imaginative product innovations reported on in 2019 indicate the growing business sense in investing in sustainability innovation from fake sunflowers, 3-D printed houses, circular T-Shirts to green-blue jeans (Hicks & Wong, 2019).

According to Bui et al. (2017), sustainability within the mining industry should ensure that all its activities do not negatively impact the environment and society’s wellbeing (Bui, Kawamura, Kim, Prathumratana, Kim, Yoon,… & Truong, 2017). Sustainability is

defined by the United States Environmental Protection Agency (EPA) as a means “to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations” (EPA, 2020). Sustainability indicators are then defined as a “summary measure of the state of or the change in a system being measured” (Fiksel, Tarsha, Frederickson & Herbert, 2012).

The method in which mining companies particularly disclose sustainability performance is through its annual reports and other appropriate formats that would be freely accessible by stakeholders (Lee, 2017). The sustainability indicators used in these reports are derived from or associated with associations such as the Global Reporting Initiative (GRI), regulatory standards, or principles of the International Council for Mining of Metals (ICMM) (AAP, 2019).

Mining companies include case studies of innovation and technology advancements in these annual reports focused on the exploitation or operational phase (AAP, 2019). The case studies are detailed and link innovation to sustainability outcomes and results; for example, a fuel–cell haul truck can potentially reduce carbon emissions, reduce noise, improve air quality, and employment opportunities for local communities (AAP, 2019).

Although the current mining focus on innovation is reported on, the GRI prepared a report on the future trends in business, reporting, and society from now until 2025 using sustainability indicators. This report examined the sustainability data that companies are required to plan for and prepare to disclose by 2025 (GRI, 2015). The critical information to be disclosed by 2025 include the use of technology by stakeholders to access and analyse data from companies to promote accountability and transparency; ethical values and reputational impacts to guide decision-makers to assess unregulated fields such as innovative technologies; and new indicators to be developed based on impact significance and importance to stakeholders (GRI, 2015). Hence the GRI has recognised the link between sustainability, sustainability indicators and innovation, and technology.

Mining companies are subject to further reporting requirements from the Dow Jones Index, based on socially responsible businesses' investing in enhancing environmental, social, and governance performance for market stability (Kochetygova, 2015). The Dow Jones promotes sustainability investing, which is intended to balance

profit with people and the earth's needs, and the need for this type of investing principle is predicted to grow with time. The sustainability indices are expected to evolve as consumers advance to customised investments based on innovative versions of sustainability indices (Kochetygova, 2015). The Dow Jones expectation presents an opportunity for mining companies to invest in new sustainability indicators to enhance its agenda to innovate and advance its investment in new technologies.

The trend in reporting requirements from the GRI (GRI, 2015) and the Dow Jones (Kochetygova, 2015) prompt the need for reporting against sustainability performance for innovation and technology.

1.3 The Research Problem – Academic relevance

The Sustainable Development Goals (SDG) were developed from the evidence that the rate of population growth could no longer be supported by the natural resources available (Tost, Hitch, Chandurkar, Moser & Feiel, 2018). In this context, mining has many challenges from resource depletion, high production costs, negative environmental impacts, and society's pressure on implementing sustainable mining practices (Aznar-Sánchez, Velasco-Muñoz, Belmonte-Ureña & Manzano-Agugliaro, 2019). Although the mining industry has progressed with implementing sustainability initiatives to meet the SDG goals, there are still areas for improvement expected by society, such as climate change initiatives (Tost et al., 2018).

The mining sector has recognised the sustainability benefits of innovation and advances in technology such as wind-diesel hybrid power plants, solar power, and nuclear power; however, there are no specific sustainability indicators for improving innovation and technology in mining (Aznar-Sánchez et al., 2019). Aznar-Sánchez et al. (2019) also specify which sustainability indicators should be of focus in mining for the use of innovation and technology, such as indicators for environmental pollution from open-pit mines on surrounding communities, environmental impacts in ice-covered landscapes and ocean floors, and increased energy usage (Aznar-Sánchez et al., 2019).

The definition of innovation adopted by Aznar-Sánchez et al. (2019) is a novel method, process, idea, or product that benefits the sustainability of the activity undertaken, while technology is defined as scientific use understanding in the mining activity. As extracted from Aznar-Sánchez et al. (2019), the gap in research is the need for:

> The “development of specific sustainability indicators for the development of innovation and technology, based on each phase of a mine’s lifecycle, which includes different social, environmental, and economic aspects. These indicators should serve to evaluate the effectiveness in achieving sustainability objectives within the sector and to guide the planning and design process of innovation and technology”. (Aznar-Sánchez et al., 2019. p 52)

The improvement of sustainability indicators needs to be an understanding of innovation and technology. This type of work includes identifying nine planetary indicators by the Stockholm Resilience Centre that measures and shows the boundary of environmental impacts in which humans can operate (Hecht & Fiksel, 2015). Additionally, there was work done in the United States in 2003 to establish environmental indicators that would be measurable and accessible to the public (Hecht & Fiksel, 2015). The challenges of establishing these indicators were described as the integrity of data collected to support the indicator's credibility (Hecht & Fiksel, 2015).

The EPA also guides how indicators are selected and have collated a selection criteria list that includes its materiality, relevance, and transparency. The EPA noted that the indicators need to reflect performance, be cost-effectively monitored over time, and be actionable, transferable, scalable, and durable (Fiksel et al., 2012).

Morse (2015) explains why sustainability indicators are not developed quickly to suit the business. The reasons are that sustainability indicators are costly to implement, track, and monitor progress on, and non-governmental organisations face the high cost of monitoring and reviewing business performance against these indicators. Morse (2015) elaborates that the indicators may become irrelevant at some point in the business, and the existing sustainability indicators may be accepted as adequate and would not need to be changed (Morse, 2015).

1.4 The research problem

The research problem is the need for sustainability indicators in the mining sector for technology and innovation to assess sustainability performance.

1.5 The main research question

The main research question explores how sustainability indicators for innovation and technology are developed and used in the mining sector to achieve sustainability performance.

1.6 Purpose and aim of the research

The study was conducted to understand sustainability indicators for innovation and technology and determine how it contributes to improving the mining sector's sustainability.

1.7 Intended Contribution

This research contributes to refining the current academic understanding of sustainability indicators for innovation and technology within the mining sector. Additionally, the research contributes to understanding the challenges, opportunities, and critical success factors that inform the expected outcomes for success in using sustainability indicators (SIs) for innovation and technology (I&T).

1.8 Scope of the research

The research's scope was to explore SIs within mining sectors for I&T. The current use of sustainability indicators for the social, environmental, and economic factors was explored as the three main sustainability pillars, for innovation and technology aspects of sustainability in the mining sector. The study covered participants based in various locations worldwide, such as South Africa, London, Chile, Brazil, and Finland across mining commodities.

1.9 Structure of the research report

The study is arranged in chapters from 1 to 7, with tables, figures, appendices, and references. The following section gives a roadmap of the chapters.

Chapter 1 discusses the research problem in the business and academic context. Chapter 2 contains the literature review that presents a review of literature on SIs for

I&T, critical factors for success with SIs for I&T, review of the challenges and opportunities for SIs for I&T. Chapter 3 outlines the research questions and aims of the research derived from the literature review in Chapter 2. The research questions are used in subsequent chapters to ensure a golden thread of ideas. Chapter 4 contains the methodology and research design descriptions. Chapter 5 presents the results/findings of the research in the sequence of each research question. Chapter 6 discusses the literature review from Chapter 2 with the results/findings from Chapter 5. Chapter 7 concludes with a summary of the findings and what the study has found for SIs for I&T within the mining sector. The recommendations to managers, the limitations, and the suggestions for future research are made to conclude the chapters.

CHAPTER 2: LITERATURE REVIEW

The literature review covers the scope of the topic that explores SIs within mining sectors for I&T. The components of the literature review are structured in Table 1 below. The literature describes the three main sustainability pillars social, environmental, and economic indicators. Sustainability, innovation, and technology are then reviewed to view what the critical factors are for success. The literature review explores the limitations and challenges experienced in using sustainability indicators and expands into opportunities to improve sustainability indicators.

Table 1 Summary of the literature review on SIs and I&T

2.1 Introduction to Sustainability				
2.2 Review of Sustainability indicators (SIs)	2.3 Review of Sustainability Innovation and Technology (I&T)	2.4 Review of Critical factors for success with SIs and I&T	2.5 Review of the Challenges with SIs and I&T	2.6 Review of Opportunities for SIs and I&T
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2.8 Conclusion				

Source: Authors own

2.1 Introduction

The definitions of sustainability are widely expressed in literature. The origins of the concept since 1969 are included in the National Environmental Policy Act (NEPA) of 1969 that described the harmonious way that humans and nature interact to be productive and secure the future for generations to come (Fiksel, Bruins, Gatchett, Gilliland & Ten Brink, 2014). Another definition of sustainability that can resonate with both technical and non-technical practitioners is that “sustainability is the continued assurance of human health and well-being, environmental resource protection, and economic prosperity, today and for generations to come” (Fiksel et al., 2014,p 692).

The next sections define and describe sustainability indicators.

2.2 Review of Sustainability indicators (SIs)

Sustainability indicators are a means to measure the ecological, financial, and societal aspects of a business to inform decision making (Latawiec & Agol, 2015) and are covered within three pillars of social, environmental, and economic areas (Sardain, Tang & Potvin, 2016).

It is acknowledged that these three pillars do not act separately and are interdependent with a unified approach necessary to gain a holistic understanding of sustainability (Sardain et al., 2016). Santana-Medina et al. (2013) noted that SIs could have seven categories: social, economic, economic–environmental, social–economic, environmental, environmental–social, and social–economic–environmental (Santana-Medina, Franco-Maass, Sánchez-Vera, Imbernon, & Nava-Bernal, 2013). Other studies classified the indicators as environmental, social, economic, equitable, viable, liveable, and sustainable (Santana-Medina et al., 2013)

Sardian et al. (2016) explain that international organisations such as the United Nations Environment Programme (UNEP) initiated a green growth strategy to bring the three pillars together for policy planning purposes. This approach's challenge was the existing low data quality for the three pillars and the existing differences in interpretation and classification of how the three pillars integrate (Sardain et al., 2016).

Hence in this literature review, the three pillars will be discussed in an overview and then discussed separately under 2.2.2 to 2.2.4.

2.2.1 Overview of SIs

The history of indicator development began at the United Nations Earth Summit in 1992 and was reviewed over the next few years by experts for their applicability, use, and misuse (Latawiec & Agol, 2015). As Lataweic & Agol (2015) described, the purpose was to inform the fundamental relationships between the capital assets, social and ecological systems, and policy decisions (Latawiec & Agol, 2015).

The SI development trend began with the United Nations Commission on Sustainable Development (UNCSD) in 1995, and other countries followed, with national and local indicators (Rinne, Lyytimäki & Kautto, 2013). The beginning of measuring SIs started with Agenda 21 that required data for sustainability decision making (Rinne et al., 2013).

The critical characteristics of SI's are that it must be scientifically-derived, replicated, and managed, be transparent in its intended outcomes, and cost-effective (Srinivasa Rao, Kareemulla, Krishnan, Murthy, Ramesh, Ananthan, & Joshi, 2019). Sustainability indicators can be used to attain sustainability performance by planning, monitoring, and evaluation (Nogueira Zon, Jacobsen Leopoldino, Yamane & Ribeiro Siman, 2020).

Sustainability indicators also form the basis for the reports produced annually by businesses using voluntary sustainability guidance, including the Global Reporting Initiative (GRI) and the greenhouse gas protocols (Haffar & Searcy, 2018). Haffar & Searcy (2018) highlighted that voluntary reporting is challenged by the lack of standard sustainability indicators reported, which implies that corporates can report against indicators developed as self-referential that are not comparable to global trends of performance of standardised indicators (Haffar & Searcy, 2018).

Hence, business selection of appropriate sustainability indicators is subject to the local context of the assessed activity (Chong, Teo & Tang, 2016). The selection criteria are likely to be informed by the policies in place, the available data, and experts' opinions in the field (Chong et al., 2016). To make existing indicator selection more straightforward, the Environmental Protection Agency (EPA) has collated all available sources of sustainability indicators into one global sustainability indicator database, called the Database of Sustainability Indicators and Indices (DOSII) (Fiksel et al.,

2012). Indicators are also likely to be implemented if the cost of implementation is reasonable, and the method of measurement is easy to apply via a scientifically sound methodology (Bui et al., 2017).

The three main sustainability indicator pillars are described in the following sections.

2.2.2 Review of literature on Environmental SIs

Definition

The European Environmental Agency defines environmental indicators as a way in which to observe the quantity and quality of a specific phenomenon (Rahdari & Anvary Rostamy, 2015).

Discussion

The environmental impacts of activities in any business are determined through life cycle assessments of the materials that flow into and out of the system (Chong et al., 2016). Chong et al. (2016) distinguished between environmental factors and environmental indicators. An example of environmental factors is waste collection and transportation, while the available landfill area is an indicator (Chong et al., 2016). In terms of a mining business, environmental indicators' performance is a significant indicator of decisions made for operational performance (Arthur, Wu, Yago, Zhang, 2017).

Environmental indicators are designed to assess impacts such as the carrying capacity of an ecosystem, which is the maximum disruption an ecosystem can withstand without negative consequences that would be impossible to reverse (Bjørn, Margni, Roy, Bulle & Hauschild, 2016). Footprint indicators are a way in which to assess the carrying capacity of the land, air, and water and include indicators such as ecological footprint indicators, water footprint indicators, and chemical footprint indicators (Bjørn et al., 2016).

Regarding ecological footprint indicators, there are disadvantages to using ecological footprints that do not cover all types of environmental disturbances that pose a threat to environmental sustainability and do not adapt to the varying spatial resolutions required to cover large carrying capacity (Bjørn et al., 2016). One recommendation for overcoming these challenges is through life cycle assessments of activities and impacts (Bjørn et al., 2016), as highlighted by Chong et al. (2016).

An important aspect is the term technical indicator, which Chong et al. (2016) described as indicators that characterise the performance of technical systems, for example, the waste stabilisation efficiency of a waste to energy process. Technical indicators are specific to the types of technologies used (Chong et al., 2016). Technical indicators are part of this study in light of the technology impact essential to this study's scope.

Conclusion

Environmental indicator examples include landfill area, ecological footprint, water footprint, chemical footprint indicators, and technical indicators specific to the types of technologies used. A life cycle approach helps identify the environmental impacts of activities and provides a methodology to identify its environmental indicators.

2.2.3 Review of literature of Economic SIs

Definition

The definition of economic sustainability include it as a measure of economic outcomes concerning impacts on stakeholders (Arthur et al., 2017); the cost associated with securing sufficient revenue for a business over a prolonged period (Chong et al., 2016); as well as securing incomes while maintaining a balanced society (Mofidi Chelan, Alijanpour, Barani, Motamedi, Azadi, & Van Passel, 2018).

Discussion

The definitions of Arthur et al. (2017) highlight stakeholders and society in their definition of economic sustainability (Arthur et al., 2017) which is supported by Mofidi Chelan et al. (2018). While Chong et al. (2016) define sustainability as securing revenue (Chong et al., 2016). The author has selected the Mofidis Chelan et al. (2018) definition of economic sustainability with an ethical aspect of ensuring it promotes justice between and among humans and nature (Mofidi Chelan et al., 2018).

In terms of economic sustainability and technology implementation, the financial benefits need to outweigh the technology's cost to be viable. It is demonstrated by the limited use of cleaner fuels such as bio-gas, which is expensive to produce, concerning fossil fuels cheaper to obtain (Chong et al., 2016). Chong et al. (2016) describe the economic indicators for waste to energy systems as the profit or loss made in running the system, the municipal interventions of subsidies and incentives, and the risk of technical maturity (Chong et al., 2016). These examples are focused on the

interventions' financial performance with a limited scope on how social sustainability plays a role or is integrated into technology solutions.

Another example of the application of sustainability economic indicators that describe its importance is in the tourism industry. Nesticò & Maselli (2020) note that island states are faced with a lack of resources, declining fish populations, and receding coastal and beach boundaries (Nesticò & Maselli, 2020). These problems are linked to climate change and impact the local area's tourism potential (Nesticò & Maselli, 2020). The problems mentioned can act as a catalyst for entrepreneurs and other businesses' economic changes, which can start new ways of generating income and revising fiscal policies and financial investing strategies (Nesticò & Maselli, 2020). This example aligns with the definition of Mofidis Chelan et al. (2018), which connects the securing of incomes while maintaining a balanced society (Mofidi Chelan et al., 2018).

Another aspect of economic indicators, precisely, macroeconomic indicators, looks at the economy's aspects and how it changes and behaves (Pissourios, 2013). These indicators are categorised into coincident, leading, and lagging indicators. Coincident indicators change as the business changes and move with its cycle and represent the economy's current state (Pissourios, 2013). The leading indicators are used to predict outcomes of economic changes before they occur while lagging indicators show the trend based on what changes in the economy have occurred (Pissourios, 2013)

Conclusion

The definitions of economic indicators found for this study varies in the literature. The most notable factor is that the SI initiatives' financial benefits must outweigh the cost of its implementation.

2.2.4 Review of literature on Social SIs

Definition

Social sustainability aims to ensure stakeholders have their basic needs met and the overall quality of life is improved, thereby creating social capital rather than a deterioration of capital (Suopajärvi, Poelzer, Ejdemo, Klyuchnikova, Korchak & Nygaard, 2016). Social sustainability also refers to the social acceptance of the sustainability initiative. In the example of waste to energy systems, social acceptance comes with benefits that will materialise for households' free heating (Chong et al., 2016).

Discussion

The potential indicators for social sustainability include being treated equally with social inclusion through participation and protecting cultural heritage (Suopajärvi et al., 2016). In a study on Brazilian mining companies, the social sustainability indicators are focused on job creation, social development such as education, and inclusion as a positive social benefit (Alves, Ferreira & Araújo, 2018). Communities around this Brazilian mining company complained about mining impacts on their daily lives, such as noise and dust, health, and increased traffic (Alves et al., 2018). Suopajärvi et al. (2016) highlighted that communities valued a clean and healthy environment and knew that they could influence mining decisions (Suopajärvi et al., 2016).

In Brazil, the mine assisted the community faced with the challenge of not having the relevant qualified, skilled people to be employed at the mine (Alves et al., 2018). Hence the mine provided education and skills training to close the skills gap (Alves et al., 2018).

Sustainability indicators consider the impact of each activity of the business on society. If the activity produces a form of environmental pollution, the impacted communities will react since it is near the local community (Chong et al., 2016). It has been termed ‘not in my backyard’ while other social indicators include separation of waste and social acceptability of the activity (Chong et al., 2016).

The challenge with social indicators is in measuring them (Chong et al., 2016). The Database of Sustainability Indicators and Indices (DOSII) developed by the EPA allows communities to access the global list of indicators to support decision-making. The EPA intended for these indicators to assess the cost-benefit of projects and the monitoring and assessment of sustainability initiatives that the communities have a vested interest in (Fiksel et al., 2012).

Conclusion

Social indicators are developed and created from a local community need, such as the skill gap, education, and job creation. These indicators are difficult to measure or monitor effectively and must be inclusively managed with communities.

2.3 Review of Sustainability Innovation and Technology (I&T)

2.3.1 Discussion of literature on the success of SI for I&T

This section of the literature review focuses on sustainability in the mining sector and the expected outcomes of success in using SIs for I&T. It describes why mining companies have SIs, and what success looks like when mining companies achieve success with SI and I&T.

This section sets the scene for the next sections 2.3.2 onwards, on how SIs and I&T are used for determining this success.

a) Expected outcomes of mining sustainably

Govindan, 2015 has noted the numerous studies on sustainability in the mining sectors have shown the positive benefits of sustainability initiatives in mining, including health, safety, and technology. Some studies provide recommendations on how to implement sustainability in mining successfully. The implementation strategy is generic and includes better planning, enhanced environmental management, cleaners technologies, forming partnerships, stakeholder engagement, and focus on employee training programmes (Govindan, 2015).

Social sustainability in mining is aligned with a more proactive approach to sustainability (Suopajärvi et al., 2016). Mining companies disclose their performance aligned with corporate social responsibility obligations (Talbot & Barbat, 2020). It talks directly to the company's social license to operate where companies disclose the non-financial data to establish credibility as a transparent business. The disclosure also creates an impression in stakeholders' minds that the company has the environment and social interests as a priority (Talbot & Barbat, 2020).

Batterham (2017) also reiterates the mining sector's motivation to keep the mining licenses to operate. Mining has a responsibility to take care of the environment and society in which it operates, so the price is paying royalties and taxes to communities and regulators to obtain these licenses and satisfy stakeholder expectations for responsible mining (Batterham, 2017).

Organisations like the International Council for Metals and Mining (ICMM) have developed standards to control its impacts, which have tools for reviewing the performance again the SIs (Suopajärvi et al., 2016). These tools are in place due to society's awareness of mining activities and projects' negative impacts. The lack of compliance to standards such as the ICMM requirements can lead to community unrest and protest about negative impacts that go unmanaged (Suopajärvi et al., 2016). In turn, it can result in production losses and cost implications for the mine (Suopajärvi et al., 2016). Social sustainability allows communities to highlight and proactively communicate their needs rather than complaining about the social impacts after it has occurred (Suopajärvi et al., 2016)

b) Environmental Social and Governance (ESG)

The expected outcomes of having SIs are to report against an organisation's financial performance so that stakeholders in the company with a vested interest can decide whether to continue investing and to what extent the investment is likely to produce a return (Janse van Rensburg et al., 2019). Investors are now looking for non-financial information such as the company's responsibility and management of environmental and social issues to secure further their investment, where there may be ESG risks (Janse van Rensburg et al., 2019).

The consequences include regulatory non-compliance, penalties, and fines as a result of this non-compliance and damage to the company's reputation as a responsible citizen. A recent example of this effect is the 2017 #DeleteUber campaign when the company had sexual harassment claims against it (Janse van Rensburg et al., 2019). Another example is Volkswagens widely published mistakes and errors in the emissions tests of its cars (Janse van Rensburg et al., 2019).

A requirement for reporting against ESG is set by the Johannesburg Stock Exchange (JSE) for any company to remain listed on the stock exchange. The listed companies commonly use the Global Reporting Index (GRI) as the internationally accepted way of reporting annually against ESG requirements (Janse van Rensburg et al., 2019).

The non-financial topics include health and safety, which is aimed at keeping employees working safely and preventing any health impacts, both physical and mental (Ranängen & Lindman, 2017). A study by Ranängen & Lindman (2017) showed three areas that most companies are focused on for non-financial topics which include corporate governance, which is the self-regulation of the company to act transparently;

environmental matters such as water and emissions; and labour issues such as diversity (Ranängen & Lindman, 2017).

c) Technology and mining sustainably

In the mining sector, the World Economic Forum (WEF) focuses on the growing stakeholder expectations for increased focus on sustainable mining practices. It is intensified as new technologies develop, the workforce grows with younger people, and the need for fair business and value-driven decisions (Batterham, 2017).

The technological changes that are most notable in mining are transformations in the flotation processes, open-pit mining, and solvent extraction and electro-winning (Batterham, 2017). These improvements of mining processes are intended to have fewer environmental impacts. Another technology used is fracking, which changes conventional underground mining where broken material is leached to drilling and mineralisation (Batterham, 2017).

The challenges around ecological restoration in mining are the need to innovate and use technology to extract metals through leaching activities (Asr, Kakaie, Ataei, Tavakoli & Mohammadi, 2019). Batterman (2017) highlights that technology will ultimately rule our daily lives and drive the cost of mining down (Batterham, 2017).

d) Innovation and mining sustainably

Sustainability innovation is described by Juntunen et al. (2019) as improvements in the production and consumption trends of business and society that result in social, environmental, and economic benefits (Juntunen, Halme, Korsunova & Rajala, 2019).

Innovation to achieve social benefits is more effective when collaborating with external stakeholders rather than investing in generating internal ideas (Juntunen et al., 2019). External collaboration reduces the cost of investigating internal expert solutions with a limited internal stakeholder pool (Juntunen et al., 2019). An example of this is when the BMWi3 was developed through extensive external stakeholder collaboration to determine what would suit customers in the electric car space, rather than designing what the company assumed customers would desire (Juntunen et al., 2019).

Stakeholder integration strategies are necessary for sustainable innovation. Juntunen et al. (2019) describe the stakeholder strategies in detail for early integration with stakeholders, selectively integrating with stakeholders, and fine-tuning with a few stakeholders. This is summarised and interpreted by the author in Table 2 below, with

the examples to support the strategy and related category that will be reinforced for better sustainability performance of the innovation options selected.

Table 2 Stakeholder strategies for integration sustainability

Strategy	Example	Category
Engage stakeholders very early in the product development process (Juntunen et al., 2019)	This is how BMW went about developing innovations in the electric car, replacing thermoplastics with renewable material, and using recycled lightweight aluminium material (Juntunen et al., 2019)	Environmental sustainability; Economic sustainability
Using employees to come up with innovative ideas that are “under the radar” and not part of the normal work expectations (Juntunen et al., 2019)	The company Rockwool which is in the construction business, developed refugee shelters after testing the material called stone wool at rock concerts. The material was fire resistant and provided insulation from heat and cold (Juntunen et al., 2019)	Social sustainability
Strategy is to select a few targeted stakeholders that could add the most value to a specific problem (Juntunen et al., 2019)	An example is the company Ecoveritas which specialised in organic food products. The company helped to solved the problem of food waste by developing soups, broths, and jams using fruit and vegetables that would otherwise be disposed-off as waste (Juntunen et al., 2019)	Environmental sustainability
Strategy is to select stakeholders that would assist in fine-tuning an already selected innovation option to refine the design or idea. This allows the business to target specific	The company Skanska’s produced ecological friendly and affordable housing with access to public transportation ; The company Ikea developed new types of waste segregation kits	Social sustainability Environmental sustainability

customer bases (Juntunen et al., 2019).		

2.3.2 Summary of the success of SI for I&T

The literature reviewed is aligned to what success looks like when using SIs and the business's outcomes. The expected outcomes for success are summarised in Table 3 as follows, extracted from the literature in 2.3.1:

Table 3 Summary of the success of SI for I&T

Success in mining using SIs and I&T	**References**
Better planning through SIs	(Govindan, 2015)
Enhanced environmental management	(Govindan, 2015)
Cleaner technologies	(Govindan, 2015)
Forming partnerships	(Govindan, 2015)
More stakeholder engagement	(Govindan, 2015)
Focus on employee training programmes	(Govindan, 2015)
Disclosing of performance	(Talbot & Barbat, 2020)
Keep the social license to operate	(Talbot & Barbat, 2020)
Establish credibility as a transparent business	(Talbot & Barbat, 2020)
Disclosure creates a positive impression in the minds of stakeholders	(Talbot & Barbat, 2020)
Satisfying stakeholder expectations for responsible mining	(Batterham, 2017)
Non-compliance to international SIs standards can lead to community unrest and protest	(Suopajärvi et al., 2016)

Prevents production losses from unrest	(Suopajärvi et al., 2016)
Allows communities to highlight and proactively communicate their needs	(Suopajärvi et al., 2016)
View of the past to predict the future	(Suopajärvi et al., 2016)
Non-financial information is required by investors	(Janse van Rensburg et al., 2019).
Keep reputation intact/ damage to the company reputation as a responsible citizen	(Janse van Rensburg et al., 2019).
Remain listed on JSE	(Janse van Rensburg et al., 2019)
Comply with GRI requirements	(Janse van Rensburg et al., 2019)
Need for fair business and value-driven decisions	(Batterham, 2017)
Improvements in mining processes to have less environmental impacts	(Batterham, 2017)
Need to innovate and use technology to reduce costs	(Batterham, 2017)
Improvements in the production and consumption trends	(Juntunen et al., 2019)
External collaboration reduces the cost of investigating internal expert solutions	(Juntunen et al., 2019)
Stakeholder integration strategies necessary for sustainable innovation	(Juntunen et al., 2019)

2.3.3 Conclusion on successful outcomes

Successful outcomes are the first element of a conceptual framework of the literature on sustainability indicators for innovation and technology. This framework will be

developed as the literature review progresses. Given the focus of the literature on successful outcomes, this is selected as the first element of the framework:

Figure 1 Successful outcomes of SIs and I&T

Source: Authors own

2.4 Review of critical factors for success with SIs and I&T

2.4.1 Discussion of literature on critical factors for success with SIs and I&T

a) Introduction

The critical factors for success for SIs for I&T have been discussed in two layers, with the first giving an overview of critical factors for success with SIs in general, and then using recent literature on critical factors for success with SIs for I&T specifically. The SI general success factors were essential, before relating it to I&T specific factors.

b) The use of SIs

SIs need to give a complete picture of the business's issues and accurately reflect these issues (Rinne et al., 2013). The critical factors for success are understanding how SIs are used since they can show the cause and effect of using resources and show the status of resources used (Santana-Medina et al., 2013). SI data needs to be able to show trends and patterns of data to assess the costs and benefits over time (Santana-Medina et al., 2013). The data coming from the SI monitoring must be easy to understand and use to make decisions (Rinne et al., 2013).

SI also needs to reflect on what is happening in the social context that represents the interests and views of stakeholders that are impacted (Santana-Medina et al., 2013).

This approach is essential when developing SIs. Experts can develop SI's in the field to link socio-ecological systems' performance (Banos-González, Martínez-Fernández & Esteve-Selma, 2016). SIs cannot be standalone or static and need to work within a model or system that links to other indicators, and the adverse effects on each indicator can then be seen (Banos-González et al., 2016).

c) Developing SIs

The development of SIs has been covered in this section and recent literature has been scarce on the development of SIs for I&T specifically.

In terms of developing SI's, there are two ways: through experts in the field and a participatory approach with stakeholders. The experts are informed by science, experience, technical knowledge on their specialised areas, and the downside is that it is one-dimensional and does not give the whole sustainability picture (Santana-Medina et al., 2013).

The participatory approach covers local context and knowledge areas that experts may miss (Santana-Medina et al., 2013). It gives value to what perspectives are of communities, and the level of participation ranges from minimal consultation to highly participatory (Santana-Medina et al., 2013). The high participatory approach is critical in communities living in protected areas with cultural and environmental rights (Santana-Medina et al., 2013). However, in most cases, communities have not been given the full benefit of inclusion in decision-making (Santana-Medina et al., 2013).

There must be a social valuation process built into the process for community participation. One such framework is the "Adaptive Learning Framework for the Development of Sustainability Indicators with Local Communities" (Santana-Medina et al., 2013). The approach supports the local context, understanding community perspectives, selecting and measuring decisions with communities (Santana-Medina et al., 2013).

d) Use of I&T for SIs in mining

The digital age and digitisation are increasingly essential features within the mining sectors (Shvedina, 2020) and are discussed in this section. The idea is that digital technologies will increase the effectiveness and efficiency of monitoring, tracking, and measuring SIs (Shvedina, 2020). In large mining companies, the diverse selection and multi-technology approach are likely to include robotic automation and sensor devices on equipment (Shvedina, 2020).

e) Ethical and Cultural factors of SIs

Gomes et al. (2015) describe the critical factors for enhanced business performance and highlight that ethical practices and transparent corporate governance are vital (Gomes, Kneipp, Kruglianskas, Barbieri Da Rosa, & Bichueti, 2015). Companies' decision-making cannot exclude environmental and social issues, and leaders need to understand the environmental and safety risks with economic performance (Gomes et al., 2015). There must be transparent agreements with stakeholders such as communities impacted by the economic, social, and environmental indicators (Gomes et al., 2015). The environmental aspects include biodiversity, conservation, and waste management, while social issues include health and safety (Gomes et al., 2015).

One aspect that is emerging is ensuring that human rights are protected with consideration for cultural values and customs (Gomes et al., 2015). The recent media reports on Rio Tinto destroying the 46000 year old Aboriginal caves (BBC News, 2020) is an example of cultural heritage as an indicator. The CEO of Rio Tinto has stepped down, and media reports that Rio Tinto was slow to react: "It was slow because when it knew the significance of those sites it could have reversed its position and it didn't... And it is misguided because when it cut bonuses recently it effectively put a price on something which is basically priceless and I think that that was tin-eared really. I'm not surprised that we've moved onto this stage where the chief executive felt that he had to go" BBC News, 2020.

f) Leadership and use of SIs

The geographical location of mining sectors is important when influenced by politics. Political leadership influences the development of SI's and private-public partnerships where the interests of these stakeholders are represented in the indicator (King, 2016). SI's from the environmental, social, and economic pillars can be integrated when governments from these sectors work jointly to achieve common goals (King, 2016).

The mining company's leadership quality is essential to make people feel included, foster collaboration, and support equality (Hale, Legun, Campbell & Carolan, 2019). There are opportunities for social indicators to be developed that align with leadership qualities to connect with people (Hale et al., 2019). The social indicators include socio-cultural networks such as urban and rural community issues; another social indicator assesses how groups of different people relate to each other. Leadership is necessary

for these social indicators to help groups of different people to build trust and address challenges and conflict (Hale et al., 2019).

Leaders also need to be aware of expert derived indicators' criticism when seeking experts' advice to develop indicators. Expert derive indicators can be too generic and sometimes cannot be applied effectively for measuring sustainability (Ahmad, Wong & Rajoo, 2019). Ahmed et al. (2019) note that environmental indicators need to consider that the natural resources must not be used quicker than they can be replaced or regenerated (Ahmad et al., 2019). Hence there must be a balance between all planetary boundaries of waste, biodiversity, climate change, and related systems (Ahmad et al., 2019) that leaders need awareness on.

g) Monitoring and measuring SIs through digitisation

The SI's are used to give early warning signs of limits being exceeded (Ahmad et al., 2019) through monitoring and analysis using digital data platforms and systems (Shvedina, 2020). For this to be feasible, the technology needs to connect online to give users a view of this data; this is especially important for inaccessible locations where remote sensing can be used (Shvedina, 2020). The timely transmission of data is essential via the infrastructure that connects the field and monitoring equipment (Shvedina, 2020). The monitoring data shows the deviations from the norm and where system failures can be picked (Shvedina, 2020). Deviations are explained when specific thresholds are exceeded for the monitoring of SIs (Shvedina, 2020). The monitoring is undertaken against specific thresholds; for example, monitoring the amount of chlorine gas released from a processing activity occurs against a specific amount (Shvedina, 2020). When the chlorine levels are above the threshold, a deviation is recorded (Shvedina, 2020).

Once the data has been transmitted and analysed, the person analysing this data needs to record any accuracy and quality issues that would support the data's integrity or quality (Shvedina, 2020). In this manner, quality control is assured with improving the quality continually (Shvedina, 2020). The critical components are then summarised as the physical infrastructure for monitoring, the internet connection services, and the quality control undertaken by the person receiving the data that can interpret this (Shvedina, 2020).

The following sections describe the various means of digital components and platforms that can be used for monitoring SIs:

- ***Monitoring SIs via circular economy***

Another concept that supports mining companies to achieve their sustainability goals is through a circular economy that aims to minimise waste and emissions (Okorie, Salonitis, Charnley, Moreno, Turner & Tiwari, 2018). The circular economy concept uses physical products repeatedly to recycle continually and reduce the amount of virgin material from being extracted (Okorie et al., 2018). A life cycle methodology guides the outcomes of determining the inputs and outputs from mining products and activities (Okorie et al., 2018).

Circular economies can be enhanced through digitisation via industry 4.0 (Ind.4.0) or the fourth industrial revolution phenomenon (Okorie et al., 2018). Ind.4.0 aligns with efficient automated systems and production processes, communication, and other technologies (Okorie et al., 2018). The Ind.4.0 push factors include the growing internet connectivity, the reduction in the size of infrastructure and hardware, and the enhancing capabilities of electronic sensors. How digital technologies support circular economics include the more efficient use of assets and managing resource flows and product lifecycles (Okorie et al., 2018).

- ***Monitoring SIs through digital twin platforms***

Another digital platform that can monitor the past impacts of SIs and future impacts of SIs is digital twin platforms. Digital twins are not standalone technologies and depend on other technologies to work effectively, such as access to big data or large volumes of information or artificial intelligence built into technology platforms and machine learning that allows computers to improve existing systems (Shvedina, 2020).

The digital twin platform can use 3-dimensional technology to visually depict how the environment, the infrastructure, and technology interact (Shvedina, 2020) and allow for virtual ecosystems to be built that show how monitoring of SIs can occur in real-time (Shvedina, 2020). Decision making can then occur to understand the impacts on mine production and the environment (Shvedina, 2020).

The critical factor for the digital twin capabilities is the need for wireless systems and video capabilities (Shvedina, 2020). It is crucial to have a cloud-based system that is aligned with the Internet of Things (IoT) (Shvedina, 2020). It implies that SIs need to

be monitored and measured through automated pollution monitoring, remotely controlled equipment, predictive and real-time data analysis (Shvedina, 2020).

➢ *Monitoring SIs via Artificial Intelligence (AI)*

A study was undertaken by Na et al. (2020) that uses AI to analyse annual sustainability reports and to report against SIs (Na, Lee, Choi & Kim, 2020). The study specifically focused on using AI to analyse Chief Executive Officer's (CEOs) sentiment in mining sustainability reports against a sustainability balanced scorecard. The financial and non-financial aspects are used in the balanced scorecard approach (Na et al., 2020). The CEO messages are essential since they contain the values, beliefs, and summary of its performance (Na et al., 2020). The study characterised the CEO messages under environmental perspectives, customer focus, financial matters, and corporate social responsibility (Na et al., 2020). The study found that CEO messages do not comprehensively cover the company's financial standing or the need for more transparent disclosure of performance (Na et al., 2020).

AI can also assist in data management and quality (Bienvenido-Huertas, Farinha, Oliveira, Silva & Lança , 2020). How this can be done is to fill in missing datasets on big sets of data using AI (Bienvenido-Huertas et al., 2020). AI is used for statistical analyses which can then be used for better decision making (Bienvenido-Huertas et al., 2020).

Another example of AI is in the statistical analysis of SI in tourism sustainability (Bienvenido-Huertas et al., 2020). The Tibet Autonomous Region uses neural networks to forecast ecological footprints and forecast buildings' energy and environmental behaviour (Bienvenido-Huertas et al., 2020). The artificial neural networks can also forecast missing data of municipal waste generation in developing countries (Bienvenido-Huertas et al., 2020).

➢ *Summary of SIs for I&T application*

The critical success factors for implementing digital technologies are dependent on companies setting a strategy on how this will be achieved with accompanying standards that guide its implementation, especially in large corporate mining companies (Shvedina, 2020). The infrastructure and hardware, and equipment must be available for ease of implementation. Additionally, the persons who are implementing and using the technology must be skilled enough to use the technology effectively (Shvedina, 2020).

2.4.2 Summary of the critical factors to achieve success

The following is a summary of the critical factors for success featured in section 2.4.1.

Table 4 Summary of the critical factors for success

Critical factors for success	Reference
Need to be clear, concise, and measurable	(Santana-Medina et al., 2013)
Needs to be able to show trends and patterns of data to assess the costs and benefits over time	(Santana-Medina et al., 2013)
Data coming from the monitoring of the SI must be easy to understand and use to make decisions	(Rinne et al., 2013)
Need to represent the interests and views of stakeholders that are impacted	(Santana-Medina et al., 2013)
Need to work within a model or system that links to other indicators	(Banos-González et al., 2016)
High participatory approach in developing SIs is especially important in situations such as	(Santana-Medina et al., 2013)
Technology needs to connect online to give users a view of this data and especially important for	(Shvedina, 2020)
Timely transmission of data is essential via the infrastructure that allows for connection to the field	(Shvedina, 2020)
Person analysing this data need to record any accuracy and quality issues to support the integrity	(Shvedina, 2020)
Achieve sustainability goals through a circular economy that aims to minimise waste and	(Okorie et al., 2018).
Digital twin platforms that can be used to monitor past and future impacts of SIs	(Shvedina, 2020).
SIs need to be monitored and measured through automated pollution monitoring, remotely	(Shvedina, 2020).
AI to be used for statistical analyses which can then be used for better decision making	(Bienvenido-Huertas et al., 2020)
Implementation of the digital technologies is dependent on companies setting an effective I&T	(Shvedina, 2020).
Infrastructure and hardware and equipment must be available for ease of implementation	(Shvedina, 2020).
Ethical practices and transparent corporate governance is vital	(Gomes et al., 2015)

Transparent agreements with stakeholders such as communities that are impacted	(Gomes et al., 2015)
Mining leadership is essential to make people feel included, foster collaboration, and support equality	(Hale et al., 2019).
Leadership is necessary to build trust and address challenges and conflict	(Hale et al., 2019)

2.4.3 Components of a conceptual framework

Critical factors are the second element of a conceptual framework of the literature on SIs for I&T. The literature is captured in this second element of the framework:

Figure 2 Critical Success factors for SIs and I&T

Source: Author's own

2.5 Review of the Challenges with SIs and I&T

2.5.1 Discussion of literature on the challenges when applying SIs and I&T

a) Introduction

The challenges in developing, using, measuring, monitoring, and reporting SIs are varied across industries and as a start, one of the crucial challenges is the broad definition of sustainability.

b) Definition of Sustainability

The definition of sustainability generally lacks clarity, which can lead to many interpretations of the concept that impedes a clear understanding of sustainability performance and reporting against this performance within the mining industry (Boiral & Henri, 2017). This challenge is reiterated by (Verma & Raghubanshi, 2018). The use of indicators has many challenges that include its nature, design, and context in which it is used (Cassar et al., 2013).

c) SI Interconnectedness

Separating indicators into three pillars, social, economic, and environmental, makes its use and application easier (Pissourios, 2013). A challenge with separating indicators means that interpretation is limited to the research in the specific pillar on which the indicator is focused (Pissourios, 2013). This focused application may result in scientists omitting new developments in other fields connected to the category or excluding other emerging fields (Pissourios, 2013). In the study by Ranangen & Lindman (2017) of sustainability in mining industries, sustainability's economic factors are highlighted as not being widely covered and limited to supply chain or investing in poverty elevation (Ranängen & Lindman, 2017). The SIs for environmental and economic are more methodologically defendable than the social indicators since welfare and quality of life are theoretical and not supported by a robust methodology of how it was derived (Verma & Raghubanshi, 2018).

d) Developing SIs

There are also challenges in the development of indicators that are related to strategic planning, the extent of experience in developing indicators, monitoring methods, reporting obligations, and resources available (Cassar et al., 2013)

The people tasked with developing indicators have a challenge in the development process from getting expert inputs and rolling this out to a broader audience for participation (Rinne et al., 2013). The participation of diverse stakeholders influences the type and quality of the developed indicator, and the more communities involved, the better (Rinne et al., 2013). The diversity comes in different ideologies, solutions, reasoning, opinions, and observations, to name a few. When there are limited participants or participants from one view only, the value is lost in a holistic view of value (Rinne et al., 2013). So SIs are not only there to measure physical impacts; they test the norms and values of people and tie different views together (Rinne et al., 2013).

The SI development challenges can be internal and external to the organisation, developing them. Internal challenges are linked to the methodology used for developing indicators, how much importance it holds, and whether simple or complex measurements are required (Verma & Raghubanshi, 2018). The selection of the correct indicators can be a challenge to assess the weighting and ranking of importance to the measured impacts (Verma & Raghubanshi, 2018). Selecting the indicator needs to align with the plan's objectives or strategy (Verma & Raghubanshi, 2018). External challenges are related to how the SI is implemented, and this includes the availability of data to inform decisions, the policies and government that drive the implementation, and the agreement on what indicators to use (Verma & Raghubanshi, 2018).

The development of indicators is further explained as expert-led or citizen-led. The citizen-led challenges are suitable for local settings and not global arenas (Verma & Raghubanshi, 2018). Global indicators may not adapt to local changing natural environments and climate, country-specific political and social changes, and new local scientific findings (Rinne et al., 2013).

A study by Ried & Rout (2020) focused on the transparent development of SIs. The process entailed first determining the relevance of indicators for measuring the issues, the second was how useful the indicators were for application, and third, the indicators needed to be assessed for scientific validity (Reid & Rout, 2020).

e) SIs implementation

Effective implementation depends on how SI's are communicated to stakeholders (Cassar et al., 2013). The geographical location at which the SI is implemented is vital to determine the status of the economic conditions and cultural contexts in which they are used (Cassar et al., 2013). A factor that can restrict the effective use of indicators is the country's political situation (Cassar et al., 2013) and the mining company located within that country. The study showed that politicians generally accepted the need for SI's but were not instrumental in implementing or driving it (Cassar et al., 2013). Another challenge raised was that institutional organisations responsible for policy and strategy lacked in monitoring the implementation of SI initiatives (Cassar et al., 2013); hence data on SI performance is lacking.

f) SI measurement through data

Even though Agenda 21 for measuring sustainability indicators came out 20 years ago, there is still no full clarity on the best way to measure sustainability (Sardain et al., 2016). The composite or aggregated indicators are one approach (Sardain et al., 2016). Aggregated or composite indicators have some advantages, such a being able to be communicated to the public and easy to understand but will lead to loss of detail when parts of the aggregate indicators are weak, and parts are substantial that are unable to be detected (Sardain et al., 2016).

A challenge is having good quality and quantity of data for an SI and the capabilities of people applying this data (Cassar et al., 2013). The availability of recent or immediate continuous data that can be used for planning and decision making is also critical, and where this is missing, it poses a risk to decision making (Cassar et al., 2013). Some SIs are also not easily measurable, data is difficult to access, or data is not relevant to the problem that needs to be resolved (Cassar et al., 2013). SIs should be simple to calculate, have readily available data, and be scientifically derived (Verma & Raghubanshi, 2018).

Additionally, data collection can be a problem if there are no human and financial resources. The resource problem extends to designing SIs, collecting data continuously, communication methods, or even using existing SIs effectively (Cassar et al., 2013).

Indicators that give information on efficiency data also need to be interpreted correctly, leading to misunderstandings and mistakes in its application (Banos-González et al., 2016). Additionally, the measurement tools available for SIs fail to consider the complexities within the mining sector, such as the political instability, cultural values of stakeholders, and economic instability (Govindan, 2015).

g) Comparison of company sustainability performance

The need to compare sustainability performance across mining companies is for investors and shareholders to assess which companies make ethical decisions and care about sustainability issues (Boiral & Henri, 2017). The challenge is to measure companies against each other to compare and rank each company's SIs that reflect its sustainability performance (Boiral & Henri, 2017). Boiral & Henri (2017) concluded that the quest to have indicators that can be measured to compare mining companies

is impossible. It is mainly because the indicators currently are vague and varied, leading to one metric having different outcomes (Boiral & Henri, 2017).

h) External reporting of SIs

GRI indicators are widely used but are a challenge because they are not measurable or specific, with most GRI indicators being qualitative and hard to measure (Boiral & Henri, 2017). Haffar & Searcy (2018) highlighted that voluntary reporting is challenged by the lack of standard sustainability indicators reported. It implies that corporates can report against indicators developed as self-referential that are not comparable to global trends of performance of standardised indicators (Haffar & Searcy, 2018).

Data reported to external stakeholders by mining companies is required to be accurate and authentic (Janse van Rensburg et al., 2019). Low quality of data reported to stakeholders is a challenge and may need external auditors' verification before being published (Janse van Rensburg et al., 2019). A drawback of the auditing methodology is that the SI data within mining reports are aggregated and are usually complex and lengthy. An environmental performance indicator's credibility is in doubt when a segment of data is audited and not the entire dataset (Janse van Rensburg et al., 2019).

Janse van Rensburg (2019) highlighted that some mining companies did not have electronic systems for reporting and reported on data manually, which can be a challenge for capturing accurate data (Janse van Rensburg, 2019). The data management gap lacks one standardised central verification database for environmental data (Janse van Rensburg et al., 2019).

i) Transparency of performance

A KPMG report notes that most mining companies report on their sustainability performance, but the reports' credibility is in question since comparing the data in these reports cannot be done to measure how companies are faring against each other (Boiral & Henri, 2017). SIs are used to reporting this performance, and the KPMG survey found that the power dynamics within mining management teams played a role in hindering transparency of reporting against the SIs for sustainability performance. The sustainability performance reflected the interests of the mine, which could be viewed as “green washing” rather than the stakeholders (Boiral & Henri, 2017).

j) Ethical reporting

Mining companies are viewed to report information that makes a good impression on stakeholders (Talbot & Barbat, 2020). This impression management related to a company's reputation has been criticised (Talbot & Barbat, 2020). The one way is in the company not revealing poor performance against SIs that can harm its reputation or writing up the performance of SIs in a convoluted manner that cannot be understood (Talbot & Barbat, 2020). Companies can also neutralise information to justify negative consequences and blame other companies or factors for its poor SI performance (Talbot & Barbat, 2020).

k) Environmental Indicator challenges

A challenge with environmental indicators is the continued development of new indicators and the indicators remaining relevant to the consequences of the impacts (Pissourios, 2013). Useful frameworks to assess environmental indicators become necessary, and one of these frameworks is the D-P-S-I-R framework (Driving forces–Pressure–State–Impact–Response). This framework maps out the driving forces for the indicator and incorporates the state of the environment, the impacts that arise, and the response of the environment to these impacts (Pissourios, 2013). The PSR framework challenge does not address complex relationships between the driver's state and responses and policy factors (Verma & Raghubanshi, 2018).

Regarding ecological footprint indicators, there are disadvantages to using ecological footprints that do not cover all types of environmental disturbances that pose a threat to environmental sustainability and do not adapt to the varying spatial resolutions required to cover large carrying capacity (Bjørn et al., 2016).

l) Social indicator challenges

Social sustainability indicators have challenges in that SI's are too simple and dilute real social issues (Hale et al., 2019). The challenge with social indicators is in measuring them (Chong et al., 2016). There is a quality of life indicator intended to assess the quality of life of a community through a single measurement (Pissourios, 2013). This measurement is for comparing across communities, cultures, and geographies (Pissourios, 2013). The approach entails a wide array of social indicators that are aggregated to show the quality of life. This indicator's aspect is the community's psychological conditions and how they feel about quality of life aspects

(Pissourios, 2013). Examples of the quality of life indicators include the Human Development Index, the Gross National Happiness, the Quality-of-Life Index (Pissourios, 2013).

The problem with the quality of life indicators is that aggregation should be based on stakeholders' agreement, challenging to achieve within a community setting and dependant on value judgements of the information informing the indicators (Pissourios, 2013). Composite social indicators also tend to lead to results that lack transparency and are one dimensional (Pissourios, 2013). Additionally, value judgements are involved in developing social indicators, especially for sustainability measurements, decision-making, and cultural values (Reid & Rout, 2020).

A technocratic approach and technocracy as the leading approach to sustainable development as a whole leads to the development of indicators through quantification and technical acumen (Reid & Rout, 2020). This mechanistic worldview may be short-sighted in developing SI's that are useful measures to assess indicators such as the health of environmental and social systems (Reid & Rout, 2020).

The technocratic approach usually opposes the values approach (Reid & Rout, 2020). Value indicators are derived from participatory approaches with stakeholders that have identified the values that pertain to the activity or community (Reid & Rout, 2020).

The technocratic approach looks to standardise and be scientifically driven, while the values approach is qualitative and cannot be standardised (Reid & Rout, 2020). Sometimes the values approach is not representative because the selection of participants can be made to force a specific outcome; hence transparency is critical to see the benefits of this approach (Reid & Rout, 2020).

2.5.2 Summary of the challenges with SIs and I&T

The challenges are summarised from section 2.5.1 above.

Table 5 Summary of the challenges with SIs and I&T

Challenges of SIs for I&T	References
• Definition of sustainability in general lacks clarity and impedes clear understanding of sustainability performance	(Boiral & Henri, 2017)

• Three pillars of indicators means that interpretation is then limited to the research in the specific pillar	(Pissourios, 2013)
• Economic factors of sustainability are highlighted as not being widely covered	(Ranängen & Lindman, 2017).
• Indicator development process challenges in rolling out to a wider audience for participation	(Rinne et al., 2013)
• Internal challenges are linked to the methodology used for developing indicators • Challenge to assess the weighting and ranking of importance to impacts being measured	(Verma & Raghubanshi, 2018)
• External challenges are related to how the SI is implemented • The availability of data to inform decisions, the policies and government that drive the implementation	(Verma & Raghubanshi, 2018)
• Challenges in citizen led indicators only suitable for local settings and not global arenas	(Verma & Raghubanshi, 2018).
• Geographical location at which the SI is implemented is not considered • Dependant on economic conditions and cultural contexts in which they are used	(Cassar et al., 2013)
• Politicians generally accepted the need for SI's but were not instrumental in trying to implement it	(Cassar et al., 2013)
• Institutional organisations responsible for policy and strategy lacked in monitoring the implementation of SI initiatives	(Cassar et al., 2013)
• Aggregated or composite indicators will lead to loss of detail when parts of the aggregate indicators are weak and parts are strong that are unable to be detected	(Sardain et al., 2016)
• Challenge is having good quality and quantity of data for an SI • Lack of capable people that can use and apply this data	(Cassar et al., 2013)
• Data collection can be a problem if there are no human and financial resources to do it	(Cassar et al., 2013)
• Indicators that give information on efficiency data also need to be interpreted correctly or this can lead to misunderstandings and mistakes its application	(Banos-González et al., 2016).
• Measurement tools available for SIs fail to consider the complexities within the mining sector such as the political instability, cultural values of stakeholders, and economic instability	(Govindan, 2015).
• Challenge is in measuring sustainability of companies against each other to measure, compare and rank each company's SIs that reflect its sustainability performance	(Boiral & Henri, 2017)

• GRI indicators are not measurable or specific and hard to measure	(Haffar & Searcy, 2018)
• Poor quality of data reported to stakeholders is a challenge and may need verification by external auditors before being published	(Janse van Rensburg et al., 2019).
• Credibility of sustainability performance reported by mining companies are in question since cannot compare data	(Boiral & Henri, 2017)
• Possibility that mining companies are not revealing poor performance against SIs that can harm its reputation, or writing up the performance of SIs in a convoluted manner that cannot be understood • Companies can also neutralise information to justify negative consequences and blame other companies or factors for its poor SI performance	(Talbot & Barbat, 2020)
• Ecological footprints do not cover all types of environmental disturbances that pose a threat to environmental sustainability	(Bjørn et al., 2016).
• Social sustainability indicators are too simple and dilute the complexity of real social issues	(Hale et al., 2019)
• Challenge with social indicators is in measuring them	(Chong et al., 2016)

2.5.3 Components of the conceptual framework

The challenges with SIs for I&T is the third element of a conceptual framework:

Figure 3 Challenges component of the framework

Source: Author's own

2.6 Review of Opportunities for SIs and I&T

2.6.1 Discussion of literature on the opportunities for SIs and I&T

a) Introduction

The opportunities related to SIs and I&T are found in developing new SIs for I&T, adapting the way they are used, and improving its design to suit the purpose of its use. The recent literature on opportunities directly related to mining SIs for I&T is sparse.

b) Finding solutions for the existing challenges

The opportunities to overcome challenges expressed in section 2.5 include finding a way to internally build the human and financial resources to execute the SIs; establish formal procedures and mechanisms to monitor SIs; and assess solutions' effectiveness (Cassar et al., 2013). The challenges can be resolved when the private and public sectors work together with academia to find solutions (Cassar et al., 2013).

Another opportunity is to use SI's to provide a more structured way to present ideas and processes through an awareness and education system (Cassar et al., 2013). People need to be willing and interested in sustainability to use and implement them (Cassar et al., 2013). So acceptance of SIs is vital in the practical implementation, rather than dialogue about how important it is (Cassar et al., 2013). This approach can help the mining sector develop leadership focus on resolving its existing challenges with SIs and investigating opportunities for improving the mining industry's use.

c) Opportunities in developing SIs

There are core indicators widely accepted and expected by stakeholders, while the additional indicators are emerging as new interests and developments within the business (Arthur et al., 2017). The additional indicators are emerging and being identified through modern tools such as Multi-decision criteria analysis tool (MCDA) that provide a better way for decision making in the mining industry; however, the authors have noted that in 2015 the MCDA was not widely applied in the mining industry for sustainability (Govindan, 2015).

The use of modern tools to help decision-makers assess sustainability in the mining industry is a means to drive the industry's sustainability agendas (Bui et al., 2017). The way indicators can be derived and selected for any organisations is to look at the core values, and what matters to the organisation. The indicators support the organisation's

objectives and can be adjusted to any project directed at innovation and technology (Fiksel et al., 2012).

The mining industry's location and geography are essential to determine the impacts on specific communities and environments (Ranängen & Lindman, 2017). Environmental KPIs are reported in six main groups: materials used, energy, emissions, waste, water, and land impacted (Janse van Rensburg et al., 2019). Therefore, the standardised environmental data framework needs to focus on improving the data management of these six groups of environmental KPIs (Janse van Rensburg et al., 2019).

Most countries follow the same type of approach to developing indicators, with one being a participatory approach, and the second is choosing a few indicators to keep the approach simple. The third is to select indicators with existing data sets to avoid data collection, and the fourth is to keep SI's in pillars of environmental, economic, and social spaces (Sardain et al., 2016).

The participatory approach and expert-led approach to developing SIs are most common (Sardain et al., 2016), and this is a possible opportunity for a mining sector to use in developing SIs for I&T. Both approaches have advantages and disadvantages (Sardain et al., 2016). When stakeholders are not involved in developing indicators, they will not trust it as much if they were involved, and the right approach is to have a joint approach of participatory and expert-led processes to cater for the balance in the participation of diverse stakeholders (Sardain et al., 2016).

d) Technology opportunities for SIs

An example of mining technologies implemented for measuring sustainability is at Barrick using predictive data analytics to assess its environmental and safety performance (Cisco, 2016). The predictive approach to data management and analysis improves the data around energy, water, and other waste and emissions. The data is captured in real-time and generates transparency with stakeholders who can digitally access this data (Cisco, 2016).

e) Opportunity with environmental Indicators

Another indicator called ecological footprint is the ecosystem impacted that provides all the natural resources a mine requires and receives the waste and emissions impacts. An indicator that looks at the footprint impacts of a mine can assess how pollution control and mitigation are addressed (Sinha et al., 2017). The value of the

ecological footprint indicator is in its ability to be condensed into one metric for biophysical data; it can inform the carrying capacity of the ecosystem being assessed; and be communicated extensively as a metric (Sinha et al., 2017). There are various methodologies and models in which the footprint can be measured and tested against new technologies. The ecological footprint further allows for pollution impacts and mitigation measures to be tested at any point in the mine life cycle (Sinha et al., 2017)

f) Opportunities with economic indicators

There are potential economic sustainability performance indicators that are in use and can be applied by adapting this to a relevant need (Arthur et al., 2017). The economic indicators include financial data such as revenues, operating costs, employee compensation, and government levies (Arthur et al., 2017). There are also financial implications due to climate change such as carbon tax as well as local spending and local supplier's data (Arthur et al., 2017)

g) Opportunities for social indicators

Another opportunity is to apply human rights performance indicators that show the record of any human rights violations aligned to the GRI requirements (Arthur et al., 2017). Indicators related to labour and employment are useful to pursue since it focuses on decent work performance indicators for occupational health and safety, training, education, diversity and equal opportunity, and equal remuneration for women and men (Arthur et al., 2017).

h) Circular Economy opportunities

There are opportunities for mining companies to partner with other mines or stakeholders to implement a circular economy for specific waste and emissions (Balanay & Halog, 2017). One example in the literature is mining competing with farming for water and with households and the business for energy (Balanay & Halog, 2017). The circular economy and life cycle analysis allow for specific and appropriate technologies to be identified (Balanay & Halog, 2017). The use of available resources is improved, and costs are, in turn, managed efficiently. New markets can also be identified using the circular economy concept (Balanay & Halog, 2017). In addition to the environmental life cycle, the social life cycle assessment identifies any social impacts and mitigation measures instituted (Balanay & Halog, 2017).

2.6.2 Summary of the opportunities for SIs for I&T

The opportunities are summarised from section 2.6.1.

Table 6 Summary of the opportunities for SIs for I&T

Opportunities	References
• Internally build the human and financial resources to execute the SIs	(Cassar et al., 2013)
• Establish formal procedures and mechanisms to monitor SIs	(Cassar et al., 2013)
• Opportunity for mechanisms to assess the effectiveness of solutions	(Cassar et al., 2013)
• Private and public sectors work together with academia to find solutions	(Cassar et al., 2013)
• Use SI's provide a more structured way to present ideas and processes through an awareness and education system	(Cassar et al., 2013)
• Develop leadership focus on solutions for challenges with existing SIs	(Cassar et al., 2013)
• Identify additional indicators through modern tools such as MCDA	(Govindan, 2015)
• Mining to consider a participatory approach and expert-led approach to developing SIs	(Sardain et al., 2016)
• Benchmark other companies such as Barrick (predictive approach to data management and analysis/data is captured real-time generates transparency with stakeholders who can access this data digital)	(Barrick report, 2019).
• Use of a footprint indicator to measure and test new technologies	(Sinha et al., 2017)
• Opportunities to pursue economic and social indicators	(Arthur et al., 2017)
• Use the circular economy concept to allow for specific and appropriate technologies to be identified	(Balanay & Halog, 2017)

2.6.3 Components of a conceptual framework

The opportunities for SIs for I&T form the last part of the conceptual framework.

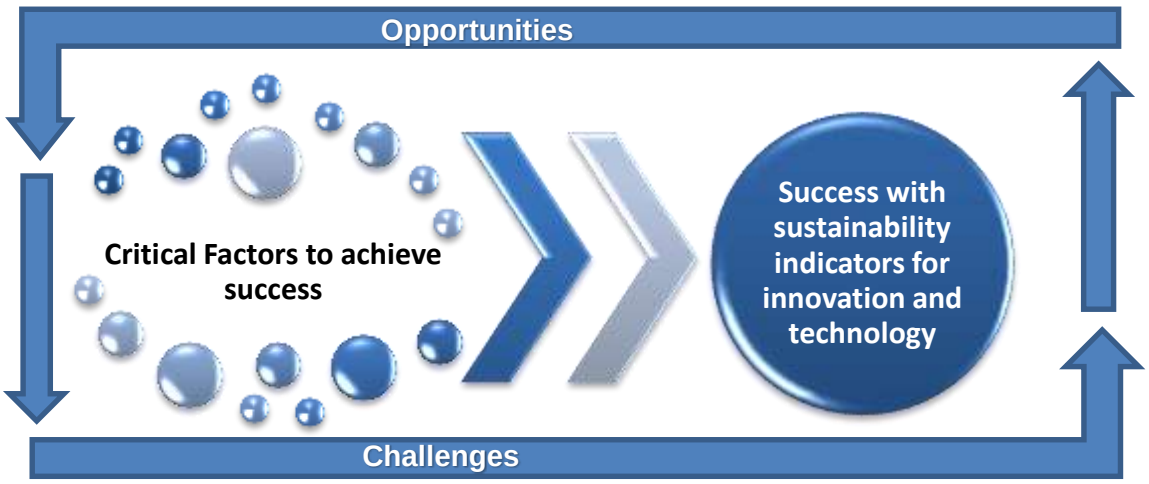

Figure 4 Opportunities within the conceptual framework

Source: Author's own

2.7 Conclusion

The literature reviewed has discussed SIs and SIs for I&T, with the outcomes for success defined and the critical supporting factors in attaining this success. The challenges and opportunities were related to success factors. The literature reviewed forms part of a conceptual model that was built on the components of the review.

CHAPTER 3: RESEARCH QUESTIONS

3.1 Introduction

The research questions were derived from the literature review in Chapter 2. Three research questions were derived for this research that was used to guide the research process.

3.2 Research question 1

How are sustainability indicators applied in the mining sector?

Research question 1 aimed to assess the use of sustainability indicators for innovation and technology in the mining industry. The question prompted the understanding of the expected outcomes for success in using SIs for I&T.

3.3 Research question 2

How is success achieved with sustainability indicators for innovation and technology?

Research question 2 aimed to identify the critical factors that influence the successful outcomes identified in research question 1. The research question covers a broad array of factors for a deeper understanding of critical factors for success.

3.4 Research question 3

How are the challenges and opportunities experienced in using sustainability indicators for innovation and technology?

Research question 3 aimed to identify the challenges and opportunities with SIs for I&T in terms of its development, identification, implementation, and future value.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

This chapter presents the methodology that was selected to undertake this research. This research process was qualitative in nature and exploratory. The methodology's research design included a defined population, unit of analysis, sampling method and size, measurement instrument, and data gathering and analysis methods. These sections are discussed with the ethical considerations and limitations included.

4.2 Philosophy

The research is exploratory and suggests a qualitative approach; hence an interpretive approach was suitable. Ospina et al. (2018) note that interpretivist researchers interact with the participants, then analyse the feedback's content and context to understand this wholistically (Ospina, Esteve & Lee, 2018).

The researcher played a vital part in interpreting the experience of the study participants (Ospina et al., 2018), and this experience was used to inform the analysis of common themes and patterns drawn from the interviews.

4.3 Approach

A qualitative approach as described by Forman et al. (2008) was used that involved getting an understanding of data collected from open-ended research questions with the selected participants (Forman, Creswell, Damschroder & Kowalski, 2008).

The goal was to understand the sustainability data collected from the open-ended research questions to selected individual participants within the mining sectors that included platinum, diamond, coal, gold, nickel, copper, and iron ore. The interviews allowed the participants to draw on their sustainability, mining, innovation, and technology space experience. The participants' answers and feedback was a process of discovery to get to findings after analysing the data collected (Forman et al., 2008).

4.4 Methodological choices

A qualitative approach was used, consisting of semi-structured interviews (Saunders & Lewis, 2012) with experienced sustainability mining professionals and experts in mining sustainability. The experienced sustainability mining professionals have roles in mining, sustainability indicators, innovation, and technology. At the same time, the experts were drawn on because of their knowledge of sustainability indicators in mining and the innovation and technology for sustainability.

The instrument used was an interview protocol to validate and confirm the meetings' practical insights with experienced mining professionals and experts in the sustainability field (Saunders & Lewis, 2012).

4.5 Purpose of research design

The purpose of the design was to align the data gathering and analysis with the research questions to create a rigorous research study.

4.6 Strategy

The strategy employed was to refine the current research conducted in sustainability indicators that can inform the design and planning of innovation and technology within the mining sectors. Refining theory aims to contribute to the existing theory (Crane, Henriques, Husted & Matten, 2016), and in this study, the potential refinements were researched from the findings.

4.7 Time horizon

This study focused on the interviews conducted in the year 2020 and focused on mining sectors that included platinum, diamond, coal, gold, nickel, copper, and iron ore. Therefore, Saunders & Lewis (Saunders & Lewis, 2012) described it as a cross-sectional study.

4.8 Techniques and procedures

The researcher planned to access and gain practical insight into sustainability indicators, innovation, and technology through semi-structured interviews with a network of sustainability professionals and experts. The data gathered from these interviews were analysed using thematic analysis (Braun & Clarke, 2006). Braun & Clarke (2006) outlined the technique used for this thematic analysis which is summarised as (Braun & Clarke, 2006):

a) Transcribing data to understand the ideas and themes;
b) Coding the data into specific features for themes;
c) Collating the codes into the themes;
d) Review the themes and arrange in levels to map it;
e) Defining the themes to form a storyline;
f) Compiling the report to form the golden thread with the rest of the research report

The process followed in this study is depicted as follows:

Figure 5 Levels of Coding to Major Themes

Source: Author's own

The inductive approach was used to code the interviews using each participant's key points for each interview question. The codes emerged and were then grouped for common meanings into categories. The inductive approach was followed once more to arrive at the themes.

Thereafter, using the conceptual framework developed in Chapter 2 a deductive approach was used to arrive at the major themes.

The software used to assist in coding the data was called Atlas.ti. The tool was used to create granular codes from the interview transcripts. It allowed the author to find the quotations linked to each code within the interview transcripts more speedily. The codes were migrated to excel in filtering out the final codes, grouping the categories and creating the themes. The codes and categories are listed in Appendix A with the themes and significant themes presented in Chapter 5.

4.8.1 Coding Process

The coding process followed the sequence shown in Figure 6. The sustainability experts and sustainability professionals were coded separately to compare the codes, categories, themes and major themes.

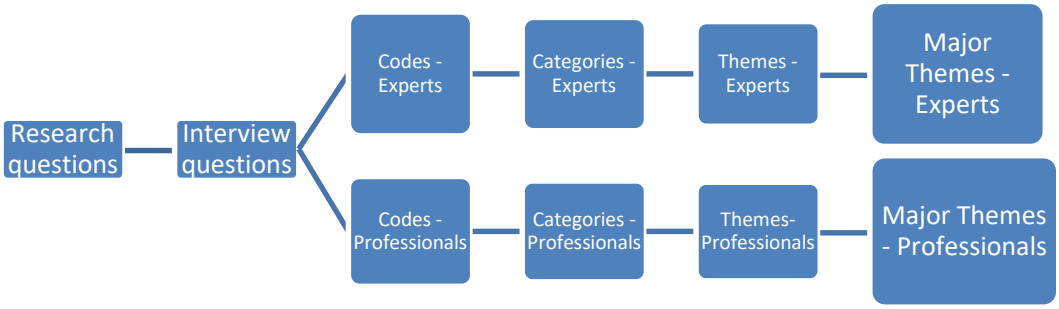

Figure 6 Coding Process Flow

Source: Author's own

4.9 Secondary Data

The non-human public data was accessed via the internet on publicly accessible websites where there is no interaction with the data provider. This data is in the form of annual sustainability reports, studies conducted by organisations such as the United States Environmental Protection Agency, and regulatory information. The data was used for information on sustainability indicators, innovation and technology, and on the mining sectors. The information from this data was used to inform the research questions.

4.10 Proposed design

4.10.1 Population/Setting

This study's population/setting was mining sectors for platinum, diamond, coal, gold, nickel, copper, and iron ore. The reason for this population/setting was to contribute to the Aznar-Sánchez et al. (2019) study which focused on mining sectors that included carbon, gold, zinc, copper, nickel, petrol, lead, iron and others, used in assessing innovation and technology for sustainable mining activity.

The population/setting that was selected specifically contributed to the gap in research on these sectors highlighted by Aznar-Sánchez et al. (2019) for the development of specific sustainability indicators for the development of innovation and technology in the mining sectors.

4.10. 2 Level of analysis

The level of analysis was mining sectors for platinum, diamond, coal, gold, nickel, copper, and iron ore.

4.10.3 Unit of analysis

The unit of analysis referred to the individuals that were selected in this study, as the professional participants interviewed and the 2 experts in the sustainability field.

4.10. 4 Sampling method and size

The sampling method chosen was a purposive sampling of selected individuals and experts in sustainability, which have experience in the mining sectors.

The selected individuals in this study met the following criteria: (a) had experience within the sectors selected. The sectors reported annually on sustainability performance using the Global Reporting Initiative (GRI), and/or international regulatory standards, are listed mining companies, and/or report against the principles

of the International Council for Mining of Metals (ICMM); (b) the individuals either worked/currently work or otherwise had experience in sustainability in the mining sector; (c) the experts currently work/worked or otherwise had experience in a specialist consulting role and/or research role in sustainability within the mining sectors.

There will be two datasets used in this study:

(Dataset 1)

- Consisting of 2 experienced sustainability mining professionals (employed within each of the 7 mining sectors selected) that have experience in one or more mining sectors. These 14 individuals will have/or had roles that are within the mining, sustainability, innovation and technology fields.
- The interviews were conducted via video calls to maximise personal interaction. The interview protocols were prepared for this dataset and submitted for ethical clearance to Gordon Institute of Business Science (GIBS) captured in Appendix B.

(Dataset 2)

- There will also be 2 sustainability experts interviewed (employed outside the mining sectors) that have experience in one or more sectors for depth of experience.
- The interviews were conducted in the same manner as dataset 1 via video calls to maximise personal interaction. The interview protocols was prepared for this dataset and submitted for ethical clearance to GIBS.

The aim is a matrix of 16 individual interviews.

Table 7 Datasets 1 and 2

Sustainability Professional	**Total Participants = 16**
1. Platinum	2 x Participants
2. Coal	2 x Participants
3. Diamonds	2 x Participants
4. Copper	2 x Participants
5. Nickel	2 x Participants
6. Iron-Ore	2 x Participants
7. Gold	2 x Participants
Sustainability Experts	
8. Across sectors	2 x Participants

A maximum of 16 interviews were planned with a minimum of 12 interviews that will be accepted as the sample size (Saunders & Lewis, 2012). After requesting a wide pool of people to be interviewed, 18 people agreed to be interviewed, with 15 professionals and 3 experts that gave written consent. The consent forms are uploaded onto the University of Pretoria's research portal.

The sample size was expected to reach data saturation (Fusch & Ness, 2015), and no new codes occurred after 12 interviews with the professionals. However, the author allowed the 15 interviews to conclude, where professionals were keen to be interviewed. The experts varied in results, and all 3 interviews were completed.

4.11 Measurement instrument

The measurement instruments included semi-structured interviews supported by interview protocols (Appendix C). The student, as the author of this study was also part of the measurement instrument. The author interviewed sustainability professionals and experts with experience in the sustainability field using the interview protocol submitted for ethical clearance.

4.12 Semi-structured interviews

The interviews allowed participants to reveal their individuality (Obodaru, 2017) and knowledge on the topic, and delve into their experience on indicators, innovation, and technology. The semi-structured interview approach undertaken by Ranängen & Lindman (2017) for sustainability management research involved individual and group interviews with the participants, with options of telephonic and written responses (Ranängen & Lindman, 2017). However, this study approach focused on video conferencing interviews with audio recordings as a backup method to record the interviews. The video and audio recordings have been loaded onto the University of Pretoria's research portal.

The semi-structured approach allowed the student to prepare the interview questions (Saunders & Lewis, 2012). These questions were used in a formal interview that was set up via the Microsoft Teams calendar invitation with location, time and venue booked. The student was conscious of professional attire and behaviour during the interview as demonstrated on the video recordings, after permission was requested to record the interview with an informed consent signed to ensure approval to be interviewed (Saunders & Lewis, 2012).

One question at a time was asked and probing questions were prepared to help the researcher get more detailed responses (Schonfeld & Mazzola, 2015). Broad exploratory questions were asked to avoid leading the participants.

The interview protocol was tested with a colleague that understood the questions and allowed the author to practice the process of asking questions. This is quality control to check the 'instrument' and the process followed. This was also an opportunity to test the two voice recorders to be used. This first test is an opportunity to correct or amend the interview approach (Saunders & Lewis, 2012).

The beginning of each interview commenced on a courteous note, and included a welcome, introduction to the research topic, and an explanation of the concent form where relevant. This made participants comfortable and clarified any expectations. An important aspect was setting a specific time and ensuring that time management was exercised to remain respectful of the participant (Saunders & Lewis, 2012)

The interview protocol was designed to obtain data on the research questions.

4. 13 Testing the measurement instrument

The first interview was tested with a colleague as a quality control check of the interview protocol. The datasets' quality was reviewed by triangulating data gathered from the interviews with professional participants and the experts.

4.14 Data gathering process

The data collection process was undertaken through interviews aligned with the interview questions.

Table 8 Research questions and interview questions

Research Question	Interview Questions
1. How are sustainability indicators applied in the mining sector?	QUESTION 1: Please tell me about what the expected outcomes are of having sustainability indicators in the mining sector? QUESTION 2: Having explained the above outcomes, are there any outcomes specific to innovation and technology? QUESTION 4: In your experience how are sustainability indicators for innovation and technology used in the mining industry?

2. How is success achieved with sustainability indicators for innovation and technology?	QUESTION 3: What are the critical factors and/or indicators that need to in place in order for you to achieve success with these innovation and technology outcomes? QUESTION 7: How would you measure the outcomes that you have expressed for innovation and technology to assess whether or not these outcomes are being met or not?
3. How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?	QUESTION 5 Part 5a: Please tell me about how you deal with the challenges experienced in using sustainability indicators for innovation and technology in the mining sector? Part 5b: How do you overcome those challenges? QUESTION 6: Please describe the opportunities you see for developing new sustainability indicators for innovation and technology in the mining sector? QUESTION 8: Looking forward, how do you see this developing over time?

4.15 Analysis approach

The data collected from the interviews were analysed after it was gathered. Braun & Clarke (2006) outline the technique used for this thematic analysis (Braun & Clarke, 2006) as explained in 4.8. The transcription of the interviews were undertaken using Microsoft Teams software as the video conferencing software. The transcripts were also loaded on the University of Pretoria's research portal.

4.16 Quality control

The qualitative study's validity and integrity is in the methodology and instruments used, and accurately representing the data collected in the study (Noble & Smith, 2015). The study's reliability is in the application of the method consistently, such as the interview methods that did not change, to ensure that it can be repeated. The researcher aims to kept records of the interviews to ensure that data is recorded, stored.

The data triangulation was conducted using the mining sustainability professionals and the sustainability expert's findings against each other (Noble & Smith, 2015). A triangulation of the professionals, experts, and literature was also conducted in Chapter 6 to compare with similarities and differences. The variances in the data and outcomes will be documented to ensure the integrity of the process is assured (Fusch & Ness, 2015).

4.17 Limitations

Qualitative research is dependent on specific methodological criteria to ensure its credibility and one of the criteria is the researcher's skill and experience (Forman et al., 2008). In this case, the student is a novice researcher with limited experience in the methodology used, for example in conducting semi-structured interviews as well as undertaking coding and thematic analysis.

Noble & Smith (2015) have highlighted that novice researchers undertaking qualitative studies are faced with the challenge of establishing consistency and validity of the results (Noble & Smith, 2015). A limitation was found in the first time use of the Atlas.ti for coding and the author migrated to excel, in completing the coding process, categories, themes and major themes. The categories were developed by grouping the frequently mentioned codes or codes with similar meaning. The limitation is that codes that did not appear frequently or have a similar meaning are potentially valuable data sources not fully explored in the study.

The unit of analysis and scope covered mainly the South African and London based professionals. There is potential for a broader scope and geography to be included in the study. The experts were based in South Africa, and there is a potential to include more expansive locations of experts.

CHAPTER 5: PRESENTATION OF THE FINDINGS/RESULTS

5.1 Introduction

The research findings are unpacked and described in this chapter, against the three research questions explained in Chapter 3.

5.2 Inductive Coding

Level 1, 2, and 3 inductive coding results for the professionals and experts are presented inTable 9. The professionals and experts form 2 datasets shown in Table 10 .

5.3 Deductive Coding

The 4th level of coding was undertaken deductively by extrapolating against the conceptual framework developed in Chapter 2. The professionals resulted in 4 major themes with 4 major themes generated for the experts shown in Table 11.

Table 9 No. of Codes, Categories and Themes

	Professionals (PAR)	Experts (EXP)
	Codes	Codes
Level 1 Inductive	307	84
	Categories	Categories
Level 2 Inductive	114	41
	Themes	Themes
Level 3 Inductive	22	8
	Major Themes	Major Themes
Level 4 Deductive	4	4

Table 10 List of Participants: Professionals and Experts

Professionals Participant No.	Sector	Experience in and/or working across these mining commodities	Country
PAR 1	Mining	platinum, copper, nickel, diamonds, iron ore and coal	United Kingdom (UK)
PAR 2	Mining	platinum, copper, nickel, diamonds, iron ore and coal	UK
PAR 3	Mining	copper	Chile
PAR 4	Mining	platinum, copper, nickel, diamonds, iron ore and coal	South Africa
PAR 8	Mining	platinum, copper, nickel, diamonds, iron ore and coal	UK
PAR 9	Mining	platinum, copper, nickel, diamonds, iron ore and coal	UK
PAR 10	Mining	platinum, copper, nickel, diamonds, iron ore and coal	UK
PAR 11	Mining	platinum, copper, nickel, diamonds, iron ore and coal	South Africa
PAR 12	Mining	platinum, copper, nickel, diamonds, iron ore and coal	Brazil
PAR 13	Mining	platinum, copper, nickel, diamonds, iron ore and coal	UK
PAR 14	Mining	platinum, copper, nickel, diamonds, iron ore and coal	South Africa
PAR 15	Mining	platinum	South Africa

PAR 16	Mining	platinum, copper, nickel, diamonds, iron ore and coal	UK
PAR 17	Mining	platinum, copper, nickel, diamonds, iron ore and coal	Finland
PAR 18	Mining	platinum, copper, nickel, diamonds, iron ore and coal	UK
Expert No.	**Sector**	**Experience in and/or working across these mining commodities**	**Country**
EXP 1	Consulting	Consulting in various mining commodities	South Africa
EXP 2	Academia	Researcher and consulting to various mining commodities	South Africa
EXP 3	Consulting	Consulting to various mining companies across commodities	South Africa

Source: Author's own

Table 11 Themes and Major Themes

Professionals		**Experts**	
Major Themes	***Themes***	***Major Themes***	***Themes***
RQ 1: *How are sustainability indicators applied in the mining sector?*			
A. Outcomes for success	1. Intended to manage impacts Environmental Social Economic	A. Outcomes for success	1. ESG value determines share price
	2. ESG value driven		2. Shareholder data transparency
	3. SIs intended to sustain a healthy life		
RQ 2: *How is success achieved with sustainability indicators for innovation and technology?*			
B. Critical success factor	1. Apply risk management principles	B. Critical success factor	1. Leadership required for SI implementation
	2. Circular economy is critical		2. Know the Cost benefits of SIs
	3. Cost benefit analysis needed		
	4. Create enabling tools/platforms/systems		
	5. I&T outcomes must be real-time, predictive, automated, digitised, artificial intelligence		
	6. Integrated approach to SI I&T implementation		
	7. Leadership commitment		
	8. Partnerships and collaboration critical to success		

	9. SIs for I&T to support community interests		
	10. Understand cultural value		
RQ3: *How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?*			
C. Challenges	1. Articulate stakeholder value	Challenge	1. Full impacts are known at closure
	2. Quality of data reported externally		2. Site level data needed
	3. Social issues are not easily measureable		3. Social SIs difficult to measure
	4. Sound measurement of impact and consequences		
	5. Drive company performance internally		
	6. Reporting transparently		
D. Opportunity	1. A Carbon Neutral future	Opportunity	1. Understand future planetary boundary
	2. Future should be human centred		
	3. Shared ownership model indicator		

Source: Authors own

5.5 Overview of the findings

This section presents the findings in the following manner:

- Professionals findings
- Experts findings
- Triangulation/comparison between the themes for professionals and experts, using each research question

Further triangulation is undertaken for the similarities and differences between the professionals, experts and literature in Chapter 6.

5.6 Findings/Results – Professionals

The findings presented in this section will discuss the themes and major themes per research question.

5.6.1 Research Q1: How are sustainability indicators applied in the mining sector?

This research question aimed to understand how sustainability indicators are applied in the mining industry concerning the three pillars of sustainability: the environmental, social, and economic areas.

The major theme that describes research question 1 is outcomes of having SI and I&T.

Major Theme A	Themes
Outcomes of SI and I&T	A1. Intended to manage impacts for environmental and social
	A2. ESG value-driven
	A3. SIs intended to sustain a healthy life

5.6.1.1 Major Theme A: Outcomes of SI and I&T

a) Theme A1: SI's intended to manage social and environmental impacts

The professionals discussed that SIs were in place to manage social and environmental impacts. The professionals mentioned that indicators were in place to manage and move toward mitigation impacts on social and environmental areas. PAR 13 discussed SIs aimed at local communities and managing impacts to protect people and the ecology as a whole. The outcomes of having SIs was clearly expressed by PAR 3, who noted that managing environmental impacts add value to the communities around mines. The environmental impacts that were raised are striving to be carbon neutral to tackle global environmental issues and aim for local ecological protection.

The aspects of safety were also raised to protect employees from fatailities an injuries. The management of social and environmental issues also covered measuring or tracking performance and targets.

PAR 13 *You know we're trying to do good for not for the mine, but for the people that we impact. Which are the local communities, which are, you know, the environment and biodiversity. You know water availability for those people, so I guess that's kind of where we're trying to get towards*

PAR 3 *If we get engaged with the community for having a solid, and responsible industry and the other of course is environmental, such that basically is an industry that contributes to face and tackle that global environmental issues in terms of habitat degradation in terms of climate change in terms of water access.*

b) Theme A2: ESG value-driven

The professionals noted that SI data sets identify problems and inform environmental, social, and governance reporting requirements. Although every professional did not use the term ESG, they mentioned at least one aspect of environmental, social, or governance issues of reporting to external stakeholders. They noted that the trends in these issues were evolving and all aimed at impact reduction onto the receiving environment to satisfy the requirements of ESG for external reporting requirements.

PAR 4 *There's definitely more focus on ESG areas from shareholders, investors, external society*

PAR 13 *I think that these targets have become kind of wide reaching. And yeah, and if we think about ESG It will yeah it will start to evolve more onto the social aspects and the governance aspects and trying to quantify the impacts of those rather than just environmental.*

The professionals mostly agreed that SIs were in place to satisfy investor needs for information used to make responsible investment decisions. The notable example was the Church of England's ethical investments and the significant impact on mining companies when a key stakeholder, such as the Church of England withdraws its

funding. The investment decisions are based on global ethical values and hence SIs are needed to show evidence against these ethical values.

PAR 12 *One way is to impress investors*

PAR 1 *Church of England's got a huge pension fund in the UK, which they hold for, you know, to the pensions of all of the Vickers and Priests and everyone's and pensions all across the country and all of the administrative staff and all of their support staff. And you know, it's an ethical investment fund because they take their religious and spiritual considerations into their investment. And so they've started to extract themselves from organisations that they feel have some kind of global ethical questions to them*

c) Theme A3: SIs intended to sustain a healthy life

The discussion on the purpose of SIs was broad and covered its overall purpose as intended to sustain a healthy life for communities that would be impacted by a mine's activities. The discussion was mostly at a local level and covered the protection of planetary boundaries from a global level, on how small impacts have a cumulative effect globally.

PAR 9 *OK, so how can we say if a mine was to come into your community, would we be able to predict the improvement in your quality of living in terms of income, educational attainment, healthy live? Healthy life years lived etc. So some of that more predictive ability to demonstrate how that really plays out to local people*

PAR 1 *And leaping to that worst-case scenario, it's difficult then to pick up the nuances of just a worsening in someone's life..*

d) Conclusion

The outcomes of having SIs and I&T are highlighted as managing environmental and social impacts, satisfying investor's needs via ESG reporting, and sustaining a healthy life for all stakeholders.

5.6.2 Research Q2: How is success achieved with sustainability indicators for innovation and technology?

This research question aimed to understand the critical factors for success for sustainability indicators applied in the mining industry.

5.6.2.1 Major Theme B: Critical Success Factors

Major Theme B	Themes
Critical success factor	B1. Apply risk management principles
	B2. Circular economy is critical
	B3. Cost-benefit analysis needed
	B4. Create enabling platforms for innovation ideas
	B5. I&T outcomes must be real-time, predictive, automated, digitised, artificial intelligence
	B6. Integrated approach to SI I&T implementation
	B7. Leadership commitment
	B8. Partnerships and collaboration critical to success
	B9. SIs for I&T to support community interests
	B10. Understand cultural value

a) Theme B1. Apply risk management principles

The discussion on risk management as a critical factor was applied to mining process changes to identify the environmental risks and social risks that could arise. The prioritisation of risk was discussed in terms of a mine identifying the most significant risks that could lead to a crisis, and developing strategies to mitigate the impacts, leading to disasters.

PAR 1 *Well, that's because you're mining quicker or your mining further or your mining deeper and you know typical risk management processes need to be applied because you're changing your process on how, but it's no different from any other expansion or change.*

PAR 9 *Never completely overcome them because nobody's got perfect foresight about what crisis is gonna happen. But it's about, you know, I think it starts with strategy and risk assessment. You know what's the strategy that you're trying to achieve as a company … All the risks that stop you from doing that.*

b) Theme B2. Circular economy is critical

The circular economy was described as a way in which waste and by-products could be recycled and reused. The discussion was on solutions to the mining industry on finding innovation methods for downstream and upstream waste management pathways.

Par 18	*You know, looking at the circular economy..to look at how we operate very differently in terms of the way that we planned. You know we're around wastes and byproducts and reusing everything so that we're kind of engineering the future landscape almost as we go along, and these kind of quite interesting concepts, and so I think there will be…And then then, I guess this is like there's a piece that that interests me, which is which is innovation downstream and more like I feel it mining industry over the last couple of decades is almost like retreated upstream.*
Par 15	*Some of those ways in which how we trade is actually started to open up at different conversations, including conversations around the circular economy*

c) Theme B3. Cost-benefit analysis needed

The importance of the cost-benefit analysis was discussed for evaluating the SIs and how much it contributes compared to how must it can cost to implement. The costs of new technologies such as a desalination plant were used; to install a desalination plant compared to buying water and what impacts this has on the environment or society.

PAR 9	*got different names for a process which is fundamentally cost benefit analysis. The principles of which were sketched out by French economist in the 1850s, the practicalities of which involving how you actually look at externalities, were resolved by an English, economist in the night in 1920. So literally, 100 years ago, you know, and the army core of Engineers in the US started using it as the basis for evaluating the value for money from their flood defence work in the early 1930s by order of an act of Congress.*
PAR 2	*Or are we gonna have a desalination plant or I was gonna buy up water that other water users aren't using in the catchment? And then you can start evaluating those both in terms of costs, an societal benefit and environmental benefit and impact and that's the sort of conversations we need to be having.*

d) Theme B4. Create enabling platforms for innovation ideas

The discussion was on creating enabling environments and platforms where the participants highlighted that mining companies need to create a safe space for employees to voice their ideas about technology and innovation ideas. The experience

behind this is that employees know the intricacies of the business better than most stakeholders.

PAR 11	*…we do want to apply innovation and technology much more and making a sort of a platform to pull out some of these ideas… Create that enabling environment that will stimulate new technology, new innovation, and new development*

e) Theme B5: SI's for I&T must be data-driven (real-time, predictive, automated, digitised, AI, remote access)

This theme featured most frequently across professionals that emphasised the importance of having data-driven digital tools and platforms to inform decisions on SIs and I&T. The professionals highlighted that SIs for I&T needed to have a focused I&T strategy for how the SI was going to be integrated into the mining operations.

The discussion was about having real-time monitoring data on SIs to have immediate understandings of impact; and predictive monitoring of the SI to understand future scenarios and plan for future impacts.

The automation of SI data was mentioned several times and the ability of the mine to use remote access and remote sensing to access the data. Artificial Intelligence (AI) was mentioned for data patterns and one particular participant acknowledged the importance of AI, but was more in favour of a human-centred approach to SIs.

The use of drones was discussed and how important this could be in monitoring environmental impacts and the ease of getting data remotely transmitted for analyses.

Another aspect of the digital theme was the digital literacy of the employees who would be managing the data to be capable and skilled at analysis and interpretation. These digitally literate employees need to communicate the risk and the leaders within the organisation need have knowledge and capabilities to use digitial platforms for decision making.

PAR 10	*"Then I think if you forecast forward then to the digital side you're then very much looking at a suite of indicators that will be based around remote sensing, remote sensing capabilities, real time data collection. And then ultimately getting into the predictive modeling type environment where you're using a*

suite of indicators to project future impact so that you can then make intervention-based changes on those processes from both an operational and, you know from a HSE or SHE or an environmental perspective"

"…need a strong, I think a strong digital literacy within the leadership group so they understand what you're driving for and why those investments in innovation that would then drive that next level performance

PAR 14 *"But in essence, we should be doing a lot more remote sensing"*

PAR 1 *"Assuming a service sector focused economy where you no longer have the same level of skills and reliance on manual labor and mining labor and so that transition to automization can have much less material negatives on a local environment, and there's an easier opportunity for mutually beneficial outcomes…"*

PAR 9 *"So I think lots of people think this its gonna head down the sort of the AI root, and there's no doubt that the vast computational power that's available now probably will allow us to do some things, but I actually hope that moves down a more human centered route actually"*

PAR 3 *"need a drone to collect data during flight and before the drone touches down again, you have already the data already in your computer because it's wireless and bluetooth"*

f) Theme B7: Leadership commitment

Leadership commitments on both messaging and accountabilities on SIs were discussed. The internal messaging and external message from mine leaders was highlighted as the key to success with SIs. The need for the message to be communicated and effected throughout the company was noted as essential to implement SIs and I&T.

One participant supported the statements made by another in the need for mining companies to recognise that the internal structures of communication between departments is crucial to understand how money is spent on sustainability, and how this translates into stakeholder value. This understanding is important to get all employees to drive the sustainability agenda of the company.

The discussion on compliance to international standards was raised that is forcing leaders in mining to take sustainability more seriously and the external reporting requires leaders to be transparent by disclosing pertinent performance information to stakeholders. Overall leaders in positions of authority are obligated to meet these disclosure requirements and show how value is derived for all stakeholders.

PAR 18 *I think it just has to be a part of the DNA of the company, and I think that you know in our company I think we're quite lucky with that today. So it's basically yeah, if you got, if you got leaders that believe in it, I think that's the probably the most important thing.*

g) Theme B8. Partnerships and collaboration critical to success

What transpired from the interviews is developing meaningful indicators in collaboration with stakeholders internally and external to mining. This will allow for sharing knowledge with communities and align the environmental and social issues. The discussion entailed sharing knowledge of technologies with communities to get buy-in and acceptance of new technologies for SI initiatives.

PAR 17 *"…so it's a cross collaborative effort, and I think that's also the challenge is that everyone's got a piece of the cake. So how do you set measures and make sure that we bring that all together and also goes for the partnership collaboration"*

PAR 3 *"…so the mining industry has the capabilities to use the most modern technology and that knowledge has to be shared with communities, so this optimizes the process of regional development"*

h) Theme B9: SIs for I&T to support/benefit communities

The professionals discussed that SIs for I&T must be aimed at benefiting communities and employees. The discussion on having mutual beneficial outcomes for stakeholders was highlighted with positive impacts on livelihoods and meeting community expectations. One participant used an example of how technology can be beneficial for communities faced with the safety risk of sourcing water from a river with crocodiles.

This was a simple use of technology with significant safety risk reduction in a local community.

The discussion centered on SIs having different outcomes at a business level and different outcomes at a community level which should be aligned. The obligation of mining companies to local communities was reiterated based on the implicit and explicit contracts in place. The implicit contracts were unspoken obligations of the mine to communities.

This is due to mines being the cause of communities converged around a mine as a means to easily access their jobs. Mining companies shaped the demographics of an area and the discussion also noted that livelihood and skills planning is necessary for mutually beneficial outcomes.

PAR 14	*I think with technology innovation that the penny is dropping. The other day they physically went and drilled a borehole for a community, for a community that's living right next to a river where there's lots of crocodiles and stuff that ends up. I think they lose about five or six people a year, which is like shocking, but they've got no choice but to go and get water from the river and then have to burn it to get it clean and cook with it. Whereas now you can imagine, I think, so that water table is right there. Drill them a hole, put up a very basic pumping system for them to actually get fresh water, which I think is so simple and yes obviously you had to get a drill rig up there, it's a fairly remote area, but still you know. So I think …there's lots of future*

i) Theme B10. Understand cultural value

The cultural value was discussed as two types of culture; one is organisational culture and the other as communities' cultural heritage. The professionals spoke of the importance of having a leadership team within mining aware and understanding the SIs related to cultural heritage is vital to business continuity. The discussion was also on having the right organisational culture and leadership mind-set to recognise that it is a challenge within the mining organisation.

PAR 1	*But like ultimately this is stuff that has to be born into the culture of the organization. So this is I guess my last point that I wanted to kind of raise and I think I'm particularly thinking about it because of what happened at Rio Tinto and the incident there and*

just yesterday read the board report that came out of that incident and some of the outcomes, which is quite interesting. And it kind of felt like cultural heritage was a symptom of a wider problem at that organization.

PAR 15 *I suppose it's experience and culture, right? So so there's years of experience, both in terms of how we've done things. The biggest challenge is how do we actually convey that?*

j) Conclusion

In summary, the critical success factors with SIs and I&T summarised in this section of the report are dependent on data-driven information systems, leadership commitment, and partnerships with local stakeholders.

5.6.3 Research Q3: How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?

Major Theme C	Themes
Challenges	C1. Articulate stakeholder value
	C2. Quality of data reported externally
	C3. Social issues are not easily measureable
	C4. Sound measurement of impact and consequences
	C5. Drive company performance internally
	C6. Reporting transparently

Some of the challenges expressed will be presented below (C1-C4) to represent a shorter section of challenges. All the themes (C1-C6) on challenges are covered in Chapter 6.

5.6.3.1 Major Theme C: Challenges

a) Theme C1: Articulate stakeholder value

The participants expressed that mining companies did not articulate stakeholder value very well. They described the problem of unclear reporting to stakeholders with a vague narrative on sustainable value. They also noted that mining companies may need to look at different ways of demonstrating value and reporting this to stakeholders.

PAR 4 *It's much more difficult to look at kind of what you know, what from a stakeholder value perspective. So looking at different projects from a stakeholder value. So that's another thing that we've been trying to do is how do we articulate the stakeholder value? So if we're looking at different water projects, if one is using water from a local river, if one is using water from the local municipality and the other ones maybe looking at water so you know which of these projects is not only better from a financial perspective for us, but also which of these projects maybe creates the most stakeholder value?*

b) Theme C2: Quality of data reported externally

The poor quality of data reported externally was highlighted and the need to make the link between SI data and technology. The challenge was described as data that was not automated and made decision-making difficult due to a time lag on receiving the manual data in nature.

PAR 10 *The ones we talked about, I still think that the biggest challenges that that by the time you've integrated the data where the chance to make an intervention or to make a decision that would impact that that change or that risk or even that opportunity but it's not always at risk is past. So if you are to get into more of a proactive preventive way of managing risk and you also want to use more of a forward looking way of even avoiding situations happening again in the 1st place. From a risk point of view or you want to harness an opportunity, for example, then I think that the way that you get that data in the ability to turn it around and make actual on the fly operational decisions becomes key*

c) Theme C3: Social issues are not easily measurable

The professionals explained that there is a challenge in measuring social issues and thereby developing and implementing SIs. One challenge was explained as the SIs mining currently implement, may have a “honey pot effect” where social initiatives attract more people around the mine who see the opportunities for a better life. Hence, the implemented SI cannot be measured effectively to see if the mine has made a difference or people are attracted to any company perceived to give more short-term benefits.

PAR 9	*"will unemployment be low in the company host communities than in a control sample of communities in South Africa, for example, as a result of our interventions on health, education and livelihoods? So, and how do you strip out honey pot effects from that? Because obviously there are jeopardy purchases because you're getting migration and so on so forth, so you know how do you actually construct the right counter factual that allows you to understand have we done a good job you know did? Did we make people's lives better? Did we increase returns for investors?"*

d) Theme C4: Sound measurement of impact and consequences

The discussion was on the challenge in managing consequences of impacts caused by the mine; and having the means to effectively track the controls of these impacts. The professionals described the difficulty in controlling individual impacts and finding a way to mitigate this. The recommendation was for mining to manage controls at an individual level through a theory of change. This was supported by other participant that noted that the design and measurement of indicators from a correct baseline was highlighted is needed and was also a challenge currently.

PAR 1	*"…if you assume the outcome of every impact control is to avoid that impact then if you do, that theory of change on the individual control, you can then start to develop indicators that build towards that outcome in a more robust way."*
PAR 15 & PAR 16	*"we know that everyting in environment is connected and there's no ring fenced areas in environment, everything is connected and it flows. So I suppose spending a little bit of money to try and understand and make use of all of those measuring systems for baselining".*
	"…you end up collecting a ton of data and it's not actually linked to what you want to measure, and you need to define your indicators first and use that to determine what data you want to actually track and capture"

5.6.3.2 Major Theme D: Opportunities

Major Theme D	Themes
Opportunity	D1: A Carbon Neutral future
	D2: Future should be human-centred
	D3: Shared beneficial/ownership model indicator

a) Theme D1: A Carbon Neutral future

The discussion on opportunities for new SIs and I&T did not yield a list of new SIs from professionals. They explained that the opportunities were in using a future-focused view and one of these is on climate change deliverables. The discussion was on driving the carbon-neutral agenda that had the 2040 and 2050 timelines.

Par 2 *: "…for example, what would that look like in terms of carbon emissions from now until 2050…Well, I think what we've put in the public domain recently is we're gonna be to 0, so already we're gonna have carbon neutral mines to 2040"*

b) Theme D2: Future should be human-centered

One participant expressed the idea of a human-centered future. This theme is highlighted because it is varied from the other professional's support of SIs for I&T. The participant noted that future SIs need to be human-centred indicators rather than I&T focused indicators and measuring how well I&T works and operates.

PAR 9 *So I think lots of people think this is gonna head down the sort of the AI root, and there's no doubt that the vast computational power that's available now probably will allow us to do some things, but I actually hope that moves down a more human centered route actually*

c) Theme D3: Shared beneficial/ownership model indicator

The discussion on shared ownership models and beneficial models was highlighted as potential solutions to transitioning communities to other livelihoods besides mining

after closure. This was highlighted as the mining sector's obligations to local communities.

PAR 1	*we owe some kind of benefit beyond saying oh here's our closure planning process. We're going to do livelihood skills planning. We're going to transition you out of the mining sector. Programs which take 5-10 years to cause a benefit maybe there's something else that's required in terms of shared ownership models. Shared beneficial models for people you know for tangible people who relied on that operation.*

d) Conclusions

The challenges expressed by participants were on how to develop stakeholder value from SIs and I&T, the current low quality of easily assessable data for decision making, and the difficulty in measuring social SIs. The opportunities presented were for a carbon-neutral future, human-centered SIs versus I&T focused SIs, and shared beneficial models in the future.

5.7 Findings/Results – Experts (EXP)

The findings will be presented. This section will discuss the interview data that informed these themes.

Themes
ESG value determines share price
Full impacts are known at closure
Leadership required for SI implementation
Know the Cost benefits of SIs
Shareholder data critical
Site level data needed
Social SIs difficult to measure
Understand future of planetary boundary impacts

5.7.1 Research Q1: How are sustainability indicators applied in the mining sector?

5.7.1.1 Major Theme A : Outcomes of SI and I&T

Major Theme A	Themes
Outcomes	A1. ESG value determines share price
	A2. Shareholder data transparency

a) Theme A1: ESG value determines share price

The experts discussed that mining companies have SIs to satisfy investors' needs and ESG reporting requirements. The success of this approach was expressed by one expert that observed the share price effects during the Covid-19 pandemic. It was noted that mining companies that complied with ESG requirements have benefited from a better share price during the pandemic, than other companies that did not comply with ESG standards.

EXP 1 *"there's enough data to prove that I think even through this pandemic. It showed that companies with a higher ESG rating although they did say the share price declined it didn't decline as much as those companies that didn't have their pulse on ESG so there's been an absolute positive correlation between sustainability and company performance"*

EXP 3 : *"I'm saying the rule book is shifting that the rule book is getting more and more sophisticated, getting more and more stringent, and therefore you have to have indicators."*

b) Theme A2: Shareholder data transparency

The experts noted that mining companies are expected to be transparent with the SI data and performance. It includes how the SIs are used, how the SIs can be accessed, and how the data is verified for credibility. The sharing of data with stakeholders was mentioned as one way in which mining companies can achieve success with SIs data transparency.

EXP 2 *So I think, um. And it's more around the transparency, so not the indicators per se, but actually what are those indicators used for? Who has access to them? Are credible all day? I think it's an increasing push towards transparency and maybe sharing of data.*

c) Conclusion

The experts expressed that mining companies used SI to achieve success with complying and reporting against ESG requirements. They highlighted the expectation that mining companies should be transparent with the SI data.

5.7.2 Research Q2: How is success achieved with sustainability indicators for innovation and technology?

5.7.2.1 Major Theme B: Critical Success factor

Major Theme B	Themes
Critical success factor	B1. Leadership required for SI implementation
	B2. Know the Cost benefits of SIs

a) Theme B1: Leadership required for SI implementation

The critical success factors discussed by experts was the need to have effective leadership to make changes and decisions on SIs and I&T. Senior leadership needed to support the SI and I&T teams within companies to drive the SI agenda. The value of SIs need to be acknowledged by leaders in positions of authority. The ability to implement, fail and improve is essential. Active input from local communities needs to be sort on their opinions, views, and experiences to progress on SIs.

EXP 2 *And then indicators that aren't perhaps sort of numbers, but where you can get, you know, hear voices or get perspectives of community.*

EXP 6 *So I think it I think the critical thing would be visionary leadership and the support of budget I think would be the critical factors.*

b) Theme B2: Know the cost benefits of SIs

The cost verse the benefits of SIs and I&T was discussed and the example of hydrogen fuels was used. The expert noted that innovation and technologies need to be implemented on the mine and play a role in bringing down the cost of fuels. The critical factor is that hydrogen cannot be implemented if it is too expensive, and hence costs drive the implementation of new technologies.

The other aspect is that funding must be accessible for I&T projects, and another critical factor is the human resources at the right competency or experience level to implement technologies.

EXP 3 *"So a lot of costs have to be put into innovation to bring down the cost of the hydrogen, yeah at the same time carbon pricing is coming up globally. I will be in South Africa and at some point when those two things meet hydrogen to make synthetic fuels will be cheaper than the way we make it a present from oil."*

EXP 2 *So I think there's sort of senior leadership buy in and support for initiatives and then associated with that, the funding.*

EXP 1 *I think another alright so critical factors. I would say there's a few it would be. You know, certainly with any technology, still gotta have the right resources on the ground too. Yeah, two things. Sufficient resources and resources of the right competency or experience. So that's number one. You still gotta have the right resources on the ground with the right knowledge to understand, support with budget*

d) Conclusion

The critical factors as explained by the experts is in the mine making an effort to get community member's perspectives and experience on SI and I&T. The other factor is understanding the business case of new technologies for SI through cost-benefit assessment.

5.7.3 Research Q3 : How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?

5.7.3.1 Theme C: Challenges

Major Themes	Themes
Challenge	C1: Full impacts are known at closure
	C2: Site level data needed
	C3: Social SIs difficult to measure

a) Theme C1: Full impacts are known at closure

The challenges according to the experts experience, is that the full impacts of mining are only realised at closure. The experience is based on the gradual effects of environmental degradation that occurs over time.

EXP 2 *And you also you know what is benefit and sort of environmental degradation from a community perspective. That's also possibly a gradual process and you're only really see the full impact at closure.*

b) Theme C2: Site level data needed

This problem is expressed as the expert explained that it was difficult to understand the status of sites and communities on an individual level. The reported SI data was consolidated into annual reports so stakeholders could not assess the actual impacts from one mine site. The discussion was on disaggregation of data to be more transparent.

EXP 2 *So I think, um. So this aggregation of data. So yes, I mean, I think you can have and more publicly available data transparent data for site level data that is happening a little bit more, especially with communities and stuff that impacts communities.*

c) Theme C3: Social SIs difficult to measure

Social SIs include the well-being and livelihood aspects of communities and employees. The challenge in social SIs is that well-being and livelihood is not easily measurable and quantifiable. There is a need to look at social SIs that reflect community complaints, grievances, unhygienic conditions and safety and health.

EXP 1 *I would think also over with if we touch on social indicators I think the change that this pandemic has brought is that keep workers employees communities or more aware of their well being and their livelihoods than before an again companies are going to have to respond to that. So again you know if an indicator was about reflecting complaints and grievances related to unhygienic conditions in workplace that's not safe and safe and healthy.*

EXP 2 *Then and then I suppose another bigger, so you giving you lots of big challenge with indicators is that that whole thing that some stuff just can't be measured. And I think specifically with social issues we wanting to measure.*

Major Theme: D	Themes
Opportunity	D1: Understand future of planetary boundary impacts

a) Theme D1: Understand future of planetary boundary impacts

The experts expressed big picture thinking is required in the mining industry to look at planetary boundary impacts. Developing SIs by looking at how mining impacts wider society verses a focused local community. The expert noted that mining leaders and management are short-sighted to progress toward an opportunity such as SIs for planetary boundary impacts.

EXP 3 *The point is to me, sustainability means that we have to be on top of. All of those other we must not exceed planetary boundaries, so I would hope that more and more peopl get out of this.*

b) Conclusion

The challenges expressed by the experts were on the SIs not being able to show the gradual impacts of environmental degradation over time, which is realised at closure. The challenge with reading annual reports was the lack of detail provided for site-level data to be able to assess actual local SI performance, hence data aggregation was a problem. The experts expressed that social SIs were not easy to measure and suggested that well-being indicators be considered. The opportunity expressed was in big picture thinking required by mining leaders on planetary boundary impacts and SIs.

5.8 Triangulation and comparison of themes: Professionals and Experts

This section is a comparison of the themes between the professionals and experts for each research question.

Section 6 further triangulates the similarities and differences between professionals, experts, and literature.

5.8.1 RQ 1: How are sustainability indicators applied in the mining sector?

The professionals highlighted managing environmental and social impacts, satisfying investor's needs via ESG reporting, and sustaining a healthy life for all stakeholders. While the experts expressed that mining companies used SI to achieve success by complying and reporting against ESG requirements and need to be transparent with the SI data to achieve success. The ESG themes resonated with both professionals and experts.

Professionals		***Experts***	
Major Themes	***Themes***	***Major Themes***	***Themes***
RQ 1: *How are sustainability indicators applied in the mining sector?*			
A. Outcomes for success	• Intended to manage impacts Environmental Social Economic	A. Outcomes for success	• ESG value determines share price
	• ESG value driven & satisfy investors		• Shareholder data transparency
	• SIs intended to sustain a healthy life		

5.8.2 RQ 2: How is success achieved with sustainability indicators for innovation and technology?

The critical factors as explained by the experts focused on two main areas of making sure communities were heard and assessing the cost benefits of new SIs for I&T. The professionals were comprehensive in the list of critical factors. The common themes were the cost-benefit analysis for SIs for I&T and the collaboration with community stakeholders. The additional themes covered by professionals include using the circular economy concept and ensuring that the I&T and SI capabilities are data-driven (real-time, predictive, automated, digitised, artificial intelligence).

Professionals		***Experts***	
Major Themes	***Themes***	***Major Themes***	***Themes***
RQ 2: *How is success achieved with sustainability indicators for innovation and technology?*			
B. Critical success factor	• Apply risk management principles	B. Critical success factor	• Leadership required for SI implementation
	• Circular economy is critical		• Know the Cost benefits of SIs
	• Cost benefit analysis needed		
	• Create enabling tools/platforms/systems		
	• I&T must be data-driven (real-time, predictive, automated, digitised, artificial intelligence		
	• Integrated approach to SI I&T implementation		
	• Leadership commitment		
	• Partnerships and collaboration critical to success		
	• SIs for I&T to support/benefit community interests		
	• Understand cultural value		

5.8.3 RQ3: How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?

The challenges that were common to both professionals and experts are the data quality and that social SIs are difficult to measure. The common theme also aligned with big picture thinking required at mining houses on planetary boundary impacts and SIs, with professionals focused on a carbon-neutral future, human-centered SIs verse I&T focused SIs, and shared beneficial models in future.

Professionals		***Experts***	
Major Themes	***Themes***	***Major Themes***	***Themes***
RQ3: *How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?*			
C. Challenges	• Articulate stakeholder value	C. Challenge	• Full impacts are known at closure
	• Quality of data reported externally		• Site level data needed
	• Social issues are not easily measurable		• Social SIs difficult to measure
	• Sound measurement of impact and consequences		
	• Drive company performance internally		
	• Reporting transparently		
D. Opportunity	• A Carbon Neutral future	D. Opportunity	• Understand future of planetary boundary impacts
	• Future should be human-centered		
	• Shared beneficial/ownership model indicator	-	

5.9 Conclusion

The ESG themes resonated with both professionals and experts; while the critical factors for success were varied and ranged from cost-benefit analysis, transparency and use of digital technologies. The challenges common to both professionals and experts are the data quality and the agreement that social SIs are difficult to measure. There were joint opportunities for planetary boundary impacts.

CHAPTER 6: DISCUSSION OF THE RESULTS/FINDINGS

6.1 Introduction

The literature reviewed in Chapter 2 is used to discuss the results from Chapter 5, and a comparison of both chapters will be undertaken. Chapter 6 follows the format and sequence of Chapter 5, where each section has a research question with the related major theme and themes. The discussion related to the problem identified in Chapter 1, and the research questions are described in Chapter 3 that were executed using the methodology in Chapter 4.

This Chapter 6 discussion entails comparing the findings and literature for similarities and differences of the research. It discusses the professionals' findings under the research questions 1, 2, and 3 against the Chapter 2 literature review; then discussing the experts' findings under research question 1, 2, and 3 against the Chapter 2 literature review. As noted in Chapter 5, the last section is the triangulation of results between the professionals, experts, and literature.

The findings will further understand the framework components that can influence modifications and enhancements to the conceptual framework.

Figure 7 Conceptual Framework

Source: Authors Own

6.2 Discussion of the results/findings– Professionals

The findings will be presented in this section in the same structure as Chapter 5.

6.2.1 Research Q1: How are sustainability indicators applied in the mining sector?

6.2.1.1 Major Theme A: Outcomes of SI and I&T

a) Theme A1: SI's intended to manage social and environmental impacts

The professionals discussed that SI's were in place to manage social and environmental impacts. The impact management was aimed at the local and global levels of protecting people and the ecology, climate, and water aspects. The literature aligned and agreed with the aims of SIs as noted by Latawiec & Agol (2015) that specify that SIs are a means to measure the ecological, financial, and societal aspects of a business to inform decision making (Latawiec & Agol, 2015). Govindan, (2015) highlights the implementation of a successful strategy for SIs includes enhanced environmental management and cleaners technologies (Govindan, 2015) to support the professional's experience. Batterman (2017) also points out the environmental and society's responsibility by mining companies (Batterham, 2017).

Key insight:

- SIs within the mining sectors intend to manage the environmental and social impacts that arise from its activities

b) Theme A2: ESG value-driven to satisfy investors

The professionals highlighted ESG as one of the key sustainability areas in mining for reporting back to shareholders, investors, and society. The participants noted that ESG would focus more on future social issues as it is currently focused more on environmental issues. The literature also aligns with the importance of ESG for SIs and I&T, and Janse van Rensburg (2019) highlight that stakeholders require non-financial information to make investment decisions. The literature further explains that ESG is

imported into companies as a way of self-regulation of the company to act transparently (Ranängen & Lindman, 2017).

Batterman (2017) notes that ESG satisfies stakeholder expectations for responsible mining (Batterham, 2017). The literature covers the need for mining companies to disclose their performance due to corporate social responsibility commitments (Talbot & Barbat, 2020). The reason for disclosure is to maintain its social license to operate and establish credibility as a transparent business (Talbot & Barbat, 2020). The disclosure and the social licenses to operate are aligned with the professional's experience.

The requirements, as explained by the participants for ethical investments is growing. The example is the Church of England that supports the literature on disclosing SI performance to obtain external investors' financial resources. The disclosure also creates an impression in stakeholders' minds that the company has the environment and society interests as a priority (Talbot & Barbat, 2020). The participants discussed this exact point of mining to secure investments by impressing investors with SI information.

Key insights:

- ESG compliance is for awareness obligations to shareholders and society
- ESG disclosure ensures that the social licenses to operate are maintained

c) Theme A3: SIs intended to sustain a healthy life

The participants' discussion is that SIs are intended to improve and sustain the quality of life for people living around the mine, and keep people healthy and safe. This extends to income, education, and wellbeing. Ranängen & Lindman (2017) note that SIs include health and safety and is directed at keeping employees working safely and preventing any health impacts at both a physical and mental level (Ranängen & Lindman, 2017). Alves et al. (2018) showed how a Brazilian mining company focuses on social sustainability indicators for job creation, education and inclusion as a positive social benefit (Alves et al., 2018). The issues that impact the quality of life were

highlighted as noise, dust, health, and increased traffic issues which affected local communities (Alves et al., 2018). The professionals also mentioned noise and dust as impacts that need to be mitigated and managed. Other issues mentioned in the literature that can impact life quality, are waste management, where mines are located close to communities (Chong et al., 2016).

The improvement of the quality of life around the mine is possible when social challenges are understood. It implies that stakeholder integration strategies are necessary for sustainable innovation relevant to local communities (Juntunen et al., 2019). The professionals did not provide specific information on stakeholder integration strategies related to SIs identification and development but did mention stakeholder participation is essential.

Key Insights:

- SIs are intended to improve and sustain the quality of life of local communities

d) RQ1. PAR Summary of areas of similarity and difference

The similarity between the participants and the literature are presented as follows:

✓ Findings similar to literature
- Findings that are different to literature

Outcomes for success	Intended to manage impacts Environmental Social impacts ✓ Protecting people and the environment with responsible mining
	ESG value-driven ✓ ESG performance drive ethical investments ✓ Mining must maintain its social license to operate
	SIs intended to sustain a healthy life ✓ Healthy, safe living, secure income, education, and wellbeing ✓ noise and dust as impacts

e) Conclusion

There are similarities with the literature and no differences observed in the literature reviewed. Research question 1 has culminated in key insights which will be concluded in Chapter 7.

6.2.2 Research Q2: How is success achieved with sustainability indicators for innovation and technology?

6.2.2.1 Major Theme B: Critical Success Factors

The participants' major themes were focused on critical factors for success in the implementation of SI and I&T.

a) Theme B1. Apply risk management principles

The application of risk management principles ensures that the environmental, social, and economic impacts arising from mining are correctly risk assessed to give priority to the highest risks. The literature did not delve into specific risk management principles but did suggest that risk can be managed through useful quality data . Low quality poses a risk to decision-making (Cassar et al.2013). SI data needs to show trends and patterns to assess the costs and benefits of SIs over time (Santana-Medina et al., 2013).

Key insights:

- Apply risk management principles for priority impact management

b) Theme B2: Circular economy is critical

The management of waste and material from the mine should be done via a circular economy concept of recycling and reuse, with the solutions in innovative methods for downstream and upstream waste management pathways. The literature discussed the circular economy as repeatedly using physical products to continually recycle and reduce virgin material from being extracted (Okorie et al., 2018). It is noted that the critical aspect of implementing a circular economy is its enhancement through digitisation for efficiency on the use of assets and resources (Okorie et al., 2018).

Key insights:

- Management of waste and material from the mine should be done via a circular economy

c) Theme B3. Costs-benefit of SIs to be analysed

The professionals highlighted the importance of understanding the cost verse benefits of having SIs and I&T initiatives. The literature supports understanding of costs and benefits but is more comprehensive in the types of benefits that SIs provide. The benefits include use of SIs to demonstrate the status of resources and reduce the number of measurements needed to account for sustainability issues (Santana-Medina et al., 2013).

SIs show cause and effects of impacts and reflect what is happening in the social context with interests and views of stakeholders (Santana-Medina et al., 2013). The SI's need to be clear, concise, and measurable and adapt to changes of the impacts it is intended to measure (Santana-Medina et al., 2013). The SI's data also needs to show trends and patterns of data to assess the costs and benefits over time (Santana-Medina et al., 2013).

One of the definitions of economic SIs introduced it, showing the cost associated with securing sufficient revenue for a business over a prolonged time (Chong et al., 2016). The cost aspects of the literature were more in-depth and more comprehensive than the participant's experience. The development of SIs has been associated with cost-effective development methods (Srinivasa Rao et al., 2019). The literature also noted that indicators are more likely to be implemented if the implementation cost was realistic to the situation (Bui et al., 2017).

A key point of the cost was selecting and implementing new technologies where the benefits needed to outweigh the technology selection cost (Chong et al., 2016). This sentiment resonated with some participants where the cost of the technology needs to be understood. Fiskel et al. (2014) noted that the EPA intended for SIs to be used for assessing the cost-benefit of projects (Fiksel et al., 2012).

Another aspect of cost was community protests and unrest due to negative impacts on communities , which can then hinder mines' production capacities, leading to a loss of working hours and profit (Suopajärvi et al., 2016). One of the participants mentioned that mining currently keeps a record of the unrest activity and this can only be measured in terms of project or production stoppages.

Additionally, the positive contribution to cost-saving was noted as the circular economy concept to recycle and prevent virgin material mining (Balanay & Halog, 2017).

Key insights:

- Cost verse benefit assessment is critical for the implementation of new technology with sustainability benefits

d) Theme B4. Create enabling tools/platforms

The participants spoke about the need for mining companies to create enabling platforms where the company should create tools and platforms that employees can use to stimulate ideas on SIs, new technology, and innovation.

The literature does not specify the tools that employees can use for contributing to ideas on SIs and I&T, however, there is mention of tools and platforms that can be used in the development of SIs and I&T. These tools apply to mining companies and are options that are available for sustainability employees to apply and identify new SIs or redesign existing SIs (Govindan, 2015). It includes modern tools such as Multi-decision criteria analysis tool (MCDA) that can enable decision making in the mining industry (Govindan, 2015). Bui et al (2017) noted that using modern tools drives the sustainability agenda by guiding decision-makers to assess sustainability in the mining industry (Bui et al., 2017).

However, Govindan (2015) warns that the measurement tools available for SIs fails to consider the complexities within the mining sector such as the political instability, cultural values of stakeholders, and economic instability (Govindan, 2015).

Another aspect of creating enabling platforms discussed by professionals is to ensure that employees who are expected to use technology are knowledgeable and data literate to understand and interpret the information generated and interpret it meaningfully. Additionally, the persons who are implementing and using the technology must be skilled enough to use the technology effectively (Shvedina, 2020).

Key insights:

- Employees need to be data literate and capable of using digital platforms for SI innovation

e) Theme B5: SI's for I&T must be data-driven (real-time, predictive, automated, digitised, AI, remote access)

This theme featured most frequently across professionals that emphasised the importance of having digitally-driven data tools to inform decisions on SIs. The electronic tools were positioned as follows:

- ***Digital data platforms and enablers***

The professionals spoke of digital data systems and platforms that would enable access to data of all decision-making types. One key aspect was the critical need to have leaders within the mining industry with high digital literacy capabilities that are able to understand what the data represents. Digitial literacy is an enabler for leaders to make decisions based on the outcomes of data. The literature explains that digital age and digitisation are increasingly essential features within mining sectors (Shvedina, 2020) and follow the participants' conversation pattern. Shvedina (2020) explains that digital technologies will increase effectiveness and efficiency of monitoring, tracking and measuring SIs (Shvedina, 2020).

Key insights:

- digital data systems/platforms enable access to data of all types for decision making

- ***Remote access and remote sensing***

The participants highlighted using drone technology to conduct environmental monitoring and transmit data directly to the user for analysis. It is one example of remote data transmissions and the accessibility of environmental monitoring. The literature supports the remote monitoring and analyses of data via technologies to connect to online systems to give users a view of this data. This is especially important for inaccessible locations where remote sensing can be used (Shvedina, 2020).

Key insight:

- use of drone technology for environmental monitoring and direct data transmission

➢ *Real-time data that allows for predictive analysis*

The participants explained that real-time information is ideal for understanding immediate impacts from environmental monitoring systems. The data is able to provide a user with immediate results of activities that cause pollution such as noise or dust that impacts communities. It further allows a user to use historical trends to predict future scenarios and make intervention-based changes on mining processes and operations. The literature aligns with this view and an example is the company Barrick that are using predictive data analytics for assessing its environmental and safety performance of mining technologies (Cisco, 2016). Barrick uses the predictive approach to improve the data around energy, water, and other waste and emissions by capturing this information in real-time (Cisco,2016). Barrick's approach is to share the data with stakeholders to generate transparency on its digital data (Barrick report, 2019).

Key insights:

- real-time information provides immediate results, enables immediate understanding impacts, and predicts future scenarios

➢ *Automation of data*

The participants discussed that automation of mining activities is viewed as reducing negative environmental impacts, however, it can have a negative impact socially when jobs are affected. Automation requires new types of skills in the workforce. There is an opportunity for mutually beneficial outcomes when new skills complement the automated systems. The literature supports that mining companies are likely to implement robotic automation in their technology strategy (Shvedina, 2020); automation to transition to Industry 4.0 (Okorie et al., 2018); and monitor pollution through automated pollution monitoring systems (Shvedina, 2020).

Key insights:

- Automation reduces negative environmental impacts, requires new types of skills in the workforce and leads to job losses

➢ *Artificial Intelligence (AI)*

AI has been described as a way to look for data patterns by participants due to its vast computational power. The literature is comprehensive on AI and notes that it can assist data management and quality with one example being to fill in missing data on datasets for statistical analyses (Bienvenido-Huertas et al., 2020). This allows for complete data trends to be analysed for decision-makers' interpretation (Bienvenido-Huertas et al., 2020). The literature also covers the use of AI to analyse Chief Executive Officer's (CEOs) sentiment contained in mining sustainability reports against a sustainability balanced scorecard (Na et al., 2020), which was not touched on by participants.

Key Insights:

- AI can be used to look for patterns in SI monitoring data

➢ *Digital Twin Platforms*

The topic of twin digital platforms that entailed monitoring past impacts of SIs and future impacts of SIs did not explicitly feature in the participants' feedback. However, digital twins depend on other technologies such as AI and monitoring of SIs in real-time (Shvedina, 2020). Like the literature, the professionals mentioned wireless systems and the Internet of Things (IoT) (Shvedina, 2020).

The literature explains that the critical success factors for implementing digital technologies are dependent on mining companies setting a firm strategy to achieve this (Shvedina, 2020). Aligned with the professionals' feedback, the relevant infrastructure, hardware, and equipment must be available for ease of implementation. Additionally, the persons who are implementing and using the technology must be skilled enough to use the technology effectively (Shvedina, 2020).

Key insights:

- Relevant infrastructure, hardware, and equipment must be available for ease of I&T implementation through the IoT

f) Theme B6. An integrated approach to SI I&T implementation

The participants spoke about mining departments working in silos and in the future will need to be more integrated to achieve sustainability outcomes. The conversation was more focused on sustainability in general rather than sustainability indicators. The literature does not talk to an integrated approach within mining companies on SIs and I&T; however, it does talk to a participatory approach in developing SIs. When all stakeholders are involved in developing SIs, they tend to trust the implementation of these SIs (Sardain et al., 2016).

Key insights:

- mining departments to be more integrated to achieve sustainability outcomes

g) Theme B7. Leadership commitment

The participants discussed the leadership commitments on both messaging and accountability for SIs. The internal and external messaging from leaders was highlighted as the key to success. Leadership concerning SIs has been described in the literature in various ways and differs from the participants' aspects. One aspect is that government leadership and political leadership influence the development of SIs (King, 2016). Effective leadership within governments must achieve specific outcomes to integrate SIs from the environmental, social, and economic pillars (King, 2016).

A participant expressed how compliance with international standards is forcing the sustainability drive in mines. It requires mines to be transparent by disclosing performance information to stakeholders. Hence leaders in positions of authority are obligated to meet these disclosure requirements and show value to stakeholders. The literature highlights that leadership is essential to make people feel included, foster collaboration, and support equality (Hale et al., 2019). The participant's focus on leadership was on disclosure and commitment to sustainability performance.

There are opportunities for social indicators that align with leadership traits (Hale et al., 2019). The types of a social indicators include one that connects socio-cultural networks such as urban and rural community issues; another social indicator is one that assesses how groups of different people relate to each other. Leadership is

necessary for these social indicators to help groups of different people to build trust and address challenges and conflict (Hale et al., 2019).

Key insights:

- Mining leadership is critical for SI disclosure, commitment to sustainability performance, messaging, and accountability

h) Theme B8. Partnerships and collaboration critical to success

What transpired from the interviews is developing meaningful indicators in collaboration with stakeholders internally and externally to mining. It will allow for sharing knowledge with communities and align the environmental and social issues. Collaboration through partnerships was described as “everyone getting a piece of the cake”. The aspects of sharing knowledge of technology use were mentioned as vitally important for regional success.

In terms of the literature, the partnerships and collaboration for SIs and I&T featured in the sustainability innovation domain to achieve social benefits (Juntunen et al., 2019). Juntunen et al. (2019) noted that it is more effective when collaborating with external stakeholders rather than investing in generating internal ideas (Juntunen et al., 2019).

There are specific stakeholder strategies that are described for innovation through stakeholder engagement and participation. The strategies include engaging stakeholders very early in the product development process (Juntunen et al., 2019); using employees to come up with innovative ideas that are not part of the normal work expectations (Juntunen et al., 2019); and adopting a strategy to select a few targeted stakeholders that could add the most value to a specific problem (Juntunen et al., 2019. This allows the business to target specific customer bases (Juntunen et al., 2019).

Key insights:

- Develop meaningful indicators through collaboration and partnerships

i) Theme B9. SIs for I&T to support/benefit communities

The participants highlighted that SIs and I&T need to add benefits to communities and not be implemented only to benefit mining. One participant explained an apt example of how I&T could make a positive difference in people's lives. He spoke of a mine providing a community with fresh drinking water by drilling underground and installing a community water pump. This simple but effective solution prevented communities from sourcing water from a river with crocodiles and was a daily safety risk for the community.

The participants spoke of the implicit social contract that mining has with communities that mines are obligated to have SIs developed for mutually beneficial outcomes. The literature reviewed did not mention implicit social contracts and provides an overall view that agrees that SI and I&T must benefit communities.

The SIs need to represent the interests and views of stakeholders that are impacted. It needs to show trends and patterns of data to assess the costs and benefits over time for all stakeholders (Santana-Medina et al., 2013). A high participatory approach in developing SIs is fundamental in communities living in protected areas with inherent value (Santana-Medina et al., 2013). The benefits can be realised in transparent agreements with stakeholders such as communities impacted (Gomes et al., 2015).

Key insight:

- There are implicit social contracts that mining have with communities that mines are obligated to have SIs developed for mutually beneficial outcomes

j) Theme B10: Understand cultural value

The participants explained culture in terms of organisational culture that ignores community cultures in the recent Rio Tinto incident, while the literature agreed and expanded on culture to include community culture and organisational culture. The literature speaks about emerging issues such as human rights that need to be protected with consideration for cultural values and customs (Gomes et al., 2015).

In terms of criticism of the SIs for the social aspects related to cultural importance, Suopajärvi et al. (2016) noted that the potential indicators for social sustainability

include protecting cultural heritage (Suopajärvi et al., 2016) which are currently lacking within mining. The decision-making in companies cannot exclude social issues and there must be transparent agreements with stakeholders such as communities that are impacted by the economic, social, and environmental indicators (Gomes et al., 2015). Additionally, the measurement tools available for SIs fails to consider the complexities within the mining sector, such cultural values of stakeholders (Govindan, 2015) and Reid & Rout (2020) highlight the importance of the cultural values to decision making (Reid & Rout, 2020).

Key insights:

- The organisational culture of mining companies must include awareness of community cultural values

k) RQ2. PAR: Summary of areas of similarity and difference

The similarity between the participants and the literature are presented as follows:

✓ Findings similar to literature
- Findings that are different to literature

B. Critical success factor	Apply risk management principles ✓ Need data-informed risk management for decision making
	Circular economy is critical ✓ Circular economy benefits waste management on the mine
	Cost benefit analysis needed ✓ Importance of understanding costs of new technology ✓ cost was due to community protests and unrest due to negative impacts on communities ✓ benefits needed to outweigh the cost for the technology selection
	Create enabling tools/platforms/systems ✓ tools and platforms important for ideas on SIs, new technology and innovation
	I&T outcomes must be real-time, predictive, automated, digitised, artificial intelligence

	✓ digital technologies will increase effectiveness and efficiency of monitoring, tracking and measuring SIs ✓ use of drone technology that is able to conduct environmental monitoring ✓ remote sensing for advanced access to data ✓ use historical trends to predict future scenarios ✓ use real-time information to enable an understanding of immediate ✓ AI assist data management ✓ wireless systems as well as the Internet of Things (IoT) ✓ relevant infrastructure, hardware and equipment must be available for ease of implementation
	Integrated approach to SI I&T implementation ✓ Participatory approach in developing SIs to enable trust of stakeholders
	Leadership commitment ✓ Leadership is important for disclosure and commitment to sustainability performance
	Partnerships and collaboration ✓ developing meaningful indicators in collaboration with stakeholders internally and external to mining
	SIs for I&T to support community interests ✓ Transparent and inclusive means to assess the costs and benefits for all stakeholders • Implicit social contracts are in place with communities
	Understand cultural value ✓ Both organisation and community culture is important

i) Conclusion

There are similarities with the literature and one difference observed in the literature reviewed. Research question 2 has culminated in key insights which will be concluded in Chapter 7.

6.2.3 Research Q3: How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?

6.2.3.1 Major Theme C: Challenges

a)Theme C1: Articulate stakeholder value

Some participants discussed the difficulty in communicating and conveying stakeholder value by mining companies. The literature outlines that stakeholders must be part of a participatory approach in developing and implementing SIs (Sardain et al., 2016). Stakeholder value can be realised during diverse stakeholders' participation that can influence the quality of the indicator developed with more communities involved in the development (Rinne et al., 2013). The diversity comes in different ideologies, solutions, reasoning, opinions, and observations and the challenge is that limited participants or participants from one view only does not ensure a holistic view of value (Rinne et al., 2013). So SI's are not only there to measure physical impacts; they test the norms and values of people and tie different views together (Rinne et al., 2013).

Key insights:

- Stakeholder value of SIs are challenging to communicate and convey by mining companies

b) Theme C2: Quality of data reported externally

The participants spoke of having the right data to make decisions timeously to allow for proactive and preventative measures to be considered to mitigate risk. The idea is to have data on leading indicators that can prevent impact versus SIs that monitor lagging indicators for better risk management. The literature defines the leading and lagging indicators for economic indicators. Pissourios (2013) notes that the leading indicators predict economic changes before they occur while lagging indicators show the trend based on what changes in the economy have occurred (Pissourios, 2013).

Both leading and lagging indicators need to be reported externally to stakeholders. The literature highlights that data reported externally by mining companies must be accurate and authentic (Janse van Rensburg et al., 2019). A weakness of reporting is that SI data within mining reports are aggregated and are usually complex and lengthy (Janse van Rensburg et al., 2019). The participants mentioned that aggregated data was not ideal and did not allow for an accurate assessment of the actual site impacts and supporting mitigation measures.

Key insights:

- There is a challenge with current mining SI data that lacks leading indicators and has aggregated data with limited site impacts

c) Theme C3: Social issues are not easily measureable

Social issues were discussed, and the participants explained that SIs implemented may have a “honey pot effect” where mines cannot measure whether they have made a difference to communities or if people gravitate toward a mining company that is perceived to do more for communities than other companies. The mining companies may invest in health, education, and livelihoods, and people will migrate toward better opportunities. The literature reviewed did not imply or cover the “honey pot effect” type of effect within the literature. The discussion was on how to measure this impact on communities in a meaningful way.

The literature has a myriad of challenges on social indicators and why it is challenging to implement. Chong et al. (2016) notes that the challenge with social indicators is in measuring them (Chong et al., 2016). The participants agreed the difficulty in measuring social indicators. There is a quality of life indicator that is intended to assess the quality of life of a community through a single measurement. This measurement is for comparing across communities, cultures and geographies. The approach entails a wide array of aggregated social indicators to show the quality of life (Pissourios, 2013). However, the problems with the quality of life indicators are that aggregation should be based on stakeholders' agreement (Pissourios, 2013).

Value judgements are involved in developing social indicators (Reid & Rout, 2020) which make them subjective. A values-oriented indicator is qualitative while other technocratic indicators approach looks to standardise and be scientifically driven. Sometimes, the values approach is not representative because participants' selection can be done to force a specific outcome (Reid & Rout, 2020).

Key insights:

- SIs implemented may have a “honey pot effect” where mines cannot measure whether they have made a difference to communities, or if people gravitate toward

a mining company that is perceived to do more for communities than other companies

d) Theme C4: Sound measurement of impact and consequences

The participants highlighted the importance of SI measurements as they noted that each impact should be managed at an individual level through a theory of change. The literature review did not include a theory of change.

The literature explained the challenges to assess the weighting and ranking of importance to impacts being measured (Verma & Raghubanshi, 2018) and that the measurement tools available for SIs fail to consider the complexities within the mining sector such as the political instability, cultural values of stakeholders, and economic instability (Govindan, 2015).

Key insights:

- Each impact should be managed at an individual level through a theory of change

e) Theme C5: Drive company performance internally

The participants expressed the need for mining companies to hold leaders to account for performance on SIs. This included adding incentives such as performance bonuses to critical tasks that drive SI into performance contracts. The mindset of leaders was another aspect of performance that participants felt was important to achieve SI goals. One participant was vocal about rooting out bad performance in the organisation where people do not align with SI deliverables.

Specifically, a participant explained that internal to the mine, the departments do not understand how sustainability translates into stakeholder value. This understanding is vital to get all employees to drive the company's sustainability agenda, so performance bonuses are needed to include SI targets effectively.

The literature review is not explicit in how employee performance is directly linked to sustainability performance, however the Rio Tinto incident is an example of action taken for sustainability incidents. Rio Tinto cut bonuses of its senior team to show that

they had effectively impacted the performance of the team. However this was seen as misguided because the cut bonuses implied that the company placed minimal value of cultural heritage transgressions (BBC News, 2020).

Key insights:

- hold leaders to account for performance on SIs through incentives such as performance bonuses to critical tasks that drive SI into performance contracts

f) Theme C6: Reporting transparently

The participants spoke about transparency and data reporting transparently with understanding where the mine has a gap in performance and then addresses this openly in external reports. This will enable the mine to change and improve its performance. The credibility of mining companies will increase if the valuation techniques of SIs are openly reported. Commitment to sustainability is more effective this way.

The literature aligns with the participants views and notes that transparency on SI performance is a challenge when SIs in mining reports cannot be compared against each other (Boiral & Henri, 2017). Boiral & Henri (2017) noted that power dynamics within mining management teams played a role in hindering transparency of reporting against the SIs for sustainability performance. The sustainability performance reflected the interests of the mine which could be viewed as “green washing” rather than the stakeholders (Boiral & Henri, 2017). The participants did not discuss the influence of power dynamics on transparency and reporting of SIs.

In terms of transparency in developing indicators, Reid and Rout (2020) noted that there are specific processes for the development of indicators that need to be followed. The process entails first determining the relevance of indicators for measuring the issues, the second was how useful the indicators were for application, and third the indicators were assessed for scientific validity(Reid & Rout, 2020). This is relevant if new indicators need to be developed in the mining industry, and participants did not include this process of developing indicators in the discussion.

Key insights:

- Existing challenge of transparently addressing poor performance on SI data

6.2.3.2 Major Theme D: Opportunities

a) Theme D1: A Carbon Neutral future

The SIs for carbon and climate change issues are mentioned as opportunities to establish indicators that would aim to meet the 2050 targets for carbon-neutral mines.

The literature covers the topic of carbon neutrality. The literature speaks to a carbon footprint indicator that is used to measure, monitor and reduce carbon emissions to the point of carbon neutrality. A carbon emissions inventory is established for the whole system that includes buildings, transport, energy systems and emissions from landfill sites. There are technologies that can be applied to monitor, control and change carbon emissions from these sources (Good et al., 2014).

Key insights:

- opportunities to establish indicators for carbon-neutral mines

b) Theme D2: Future should be human-centered

The participants discussed that SIs and I&T were an inevitable route as the world transitions to vast computational powers of computers, however one participant hoped that SIs would take a more human-centered approach than an I&T approach.

The literature speaks of opportunities to develop and apply human rights performance indicators that show the record of any human rights violations which are also aligned to the GRI requirements (Arthur et al., 2017). The literature reviewed did not have an opinion on the I&T approach verses the human-centered approach. The literature lists some indicators that are human-focused related to labour and employment, occupational health and safety, training, education, diversity and equal opportunity, and equal remuneration for women and men (Arthur et al., 2017).

Key insights:

- SIs for I&T is inevitable however one participant hoped that SIs would take a more human-centered approach rather than an I&T approach

c) Theme D3: beneficial/ownership model indicator

The idea of a shared ownership model and shared beneficial models were discussed by participants where mining has a social contract with communities. The models include SIs to assess mining companies on how much is planned for benefits beyond closure planning and livelihood skills planning. The shared beneficial model indicators can be long term plans to transition communities out of mining into a service sector economy. The idea is that as mining moves toward automation the skill need change and opportunities for mutually beneficial outcomes arise.

The literature reviewed did not mention shared beneficial models for communities after closure, or shared beneficial models due to automaton.

Key insights:

- shared ownership/beneficial models mining benefits communities beyond closure for long term plans to transition communities into a service sector economy

d)RQ3. PAR : Summary of areas of similarity and difference

The similarity between the participants and the literature are presented as follows:

✓ Findings similar to literature
- Findings that are different to literature

C. Challenges	Articulate stakeholder value ✓ a participatory approach is encouraged to ensure communication and engagement with stakeholders in to developing SIs and implementing SIs
	Quality of data reported externally ✓ leading and lagging indicators ✓ aggregated and are usually complex and lengthy
	Social issues are not easily measurable ✓ Social indicators are difficult to measure

	• "Honey pot effect" of mining benefits to communities
	Sound measurement of impact and consequences ✓ Numerous challenges in measuring SIs effectively • impact should be managed at an individual level through a theory of change
	Drive company performance internally ✓ need for performance management
	Reporting transparently ✓ transparency on SI performance in external reporting
D. Opportunity	A Carbon Neutral future ✓ carbon neutrality and footprint indicator
	Future should be human-centered ✓ Importance of human-focused indicators
	Shared ownership model indicator • shared beneficial models for communities after closure

6.3 Discussion of findings/results – Experts (EXP)

The findings will be presented in this section and discussed against the literature reviewed in the same manner as the professionals in section 6.4. This section will not repeat aspects of the literature reviewed for the professionals, but will describe the key insights, similarities, and differences of the research against the experts experience.

6.3.1 Research Q1 : How are sustainability indicators applied in the mining sector?

6.3.1.1 Major Theme A: Outcomes of SI and I&T

a) Theme A1: ESG value determines share price

The experts noted that mining companies report on SIs and I&T to meet the ESG requirements important for financial decisions and operational decision making. One expert highlighted that ESG compliant mining companies' share price did not fall as much as the companies that were not aligned with ESG requirements, and hence ESG compliance is an advantage.

The literature is aligned with the expert's experience. The listed companies report against the Global Reporting Index (GRI) as the internationally accepted way of reporting annually against ESG requirements (Janse van Rensburg et al., 2019).

Key insights:

- ESG compliance is an advantage for a better share price

b) Theme A2: Shareholder data transparency

The experts discussed the transparency and sharing of data by mining companies was one of the reasons why mining companies are obligated to report against SIs. The literature agrees with the outcomes of SIs for transparency. In addition, the study by Ranängen & Lindman (2017) showed most companies are focused on corporate governance which is self-regulation of the company to act transparently (Ranängen & Lindman, 2017).

Key insights:

- transparency and sharing of data by mining companies was one of the reasons why mining companies are obligated to report against SIs

c)RQ1. EXP : Summary of areas of similarity and difference

The similarity between the participants and the literature are presented as follows:

✓ Findings similar to literature
- Findings that are different to literature

Outcomes for success	ESG value determines share price ✓ (ESG) requirements that are important for financial decisions and operational decision making
	Shareholder data transparency ✓ transparency and sharing of data by mining companies was one of the reasons why mining companies are obligated to report against SIs

6.3.2 Research Q2: How is success achieved with sustainability indicators for innovation and technology?

6.3.2.1 Major Theme B: Critical Success factor

a)Theme B1: Leadership required for SI implementation

The experts highlighted the importance of senior leadership to support the SI and I&T teams within companies to drive the SI agenda. They expressed that the value of SIs needed to be acknowledged by leaders in positions of authority. Leaders needed to possess the ability to implement, fail and improve on SIs and I&T. Additionally, the experts noted that leaders need to acknowledge the active inputs from local communities for SIs and I&T.

The literature agreed on the feedback from experts but also elaborated on the quality of leadership in mining is essential to make people feel included, foster collaboration, and support equality (Hale et al., 2019). There are opportunities for social indicators to be developed that align with leadership qualities to connect with people and mining leadership is necessary for these social indicators to help groups of different people to build trust and address challenges and conflict (Hale et al., 2019).

Key insights:

- Leaders need the ability to implement, fail and improve on SIs and I&T

b) Theme B2: Know the cost-benefits of SIs

The cost benefit assessments of SIs and I&T was highlighted as a key factor to successful implementation. The experts specifically spoke of innovation that would bring down the cost of hydrogen as fuel, and polluters will be charged for released carbon emissions. The literature covered the costs and benefits of SIs under the outcomes for success with I&T. The cost-benefits were described as the need for and a challenge in proper use of data trends and patterns of data to assess the costs and benefits over time for progress against SIs (Santana-Medina et al., 2013).

Key insights:

- Costs are associated with new technologies like cost of hydrogen as fuel and polluters charged for carbon emissions that are released

c)RQ2. EXP : Summary of areas of similarity and difference

The similarity between the participants and the literature are presented as follows:

✓ Findings similar to literature
- Findings that are different to literature

Critical success factor	Leadership required for SI implementation ✓ Leadership to drive SI agenda ✓ active inputs from local communities for SIs and I&T • Ability to implement, fail and improve on SIs and I&T
	Know the Cost benefits of SIs ✓ Costs and benefits must be understood for SI implementation

6.3.3 Research Q3: How are challenges and opportunities experienced in using sustainability indicators for innovation and technology?

6.3.3.1 Theme C: Challenges

a)Theme C1: Full impacts decision making & mine closure

The experts discussed that one challenge with SIs and impact management is that the impacts in mining companies happen gradually and the full impact is only realised at mine closure.

The literature speaks about full impact decision making that is possible when the participatory approaches of developing and implementing SIs are followed (Santana-Medina et al., 2013). This includes local context and knowledge of communities and gives communities the chance to benefit from inclusion in decision making (Santana-Medina et al., 2013).

Key insights:

- impacts in mining companies happen gradually and the full impact is only realised at mine closure

b) Theme C2: Site level data needed

The experts' issues as a frustration by the experts are that the annual reports of mining companies only report aggregated data and hence site level data cannot be accessed or reviewed by external stakeholders. The site level data is required to allow communities to assess the impacts on the surroundings and the mines show that they are transparent with the data.

The literature speaks of aggregated data that is also difficult to measure and interpret (Sardain et al., 2016). The literature explains that mining companies prefer aggregated or composite indicators that have advantages, such as communicating to the public in a simplified manner easy. However, this leads to loss of detail when parts of the aggregate indicator are weak and parts are strong (Sardain et al., 2016).

Key insights:

- aggregated data in annual reports of mining companies have little value to external stakeholders that are interested in site level impacts

c) Theme C3: Social SIs are difficult to measure

The other challenge that the experts spoke about was the difficulty in measuring social SIs. The literature is comprehensive Chong et al (2016) notes that the challenge with social indicators is in measuring them (Chong et al., 2016).

The SI indicator called the “quality of life” indicator is hard to measure. Social indicators need to be based on stakeholders' agreement, which is challenging to achieve within a community setting (Pissourios, 2013). The experts did no raise this point on the agreements required for SIs from the community.

The social sustainability indicators also have challenges as described by Hale et al. (2019) in that SI’s that are too simple dilute the complexity of real social issues (Hale

et al., 2019). The experts noted the difficulty of measuring social indicators but not why it was complicated beyond data aggregation.

Key insights:

- Social indicators are difficult to measure

6.3.3.2 Theme D: Opportunities

a) Theme D1: Understand future of planetary boundary impacts

The experts explained the concept of future planetary boundaries and not exceeding this. The literature says that a balance must be maintained between all planetary boundaries of waste, biodiversity, climate change, and related systems (Ahmad et al., 2019). The SI's are used to give early warning signs of limits being exceeded (Ahmad et al., 2019). The experts and literature are well aligned to this view.

Key insights:

- Opportunity for a future planetary boundaries indicator

c)RQ3. EXP : Summary of areas of similarity and difference

The similarity between the participants and the literature are presented as follows:

✓ Findings similar to literature
- Findings that are different to literature

Challenges	Full impacts are known at closure ✓ full impact decision making • impacts in mining companies happen gradually, and the full impacts only realised at mine closure
	Site level data needed ✓ aggregated data is not ideal when site level data cannot be accessed
	Social SIs difficult to measure ✓ difficulty in measuring social SIs
Opportunity	Understand future planetary boundary ✓ balance must maintained and all between planetary boundaries

6.4 Triangulation and comparison of the Professionals and Experts major themes

This section shows the culmination of the similarities and differences between the professionals, experts and literature.

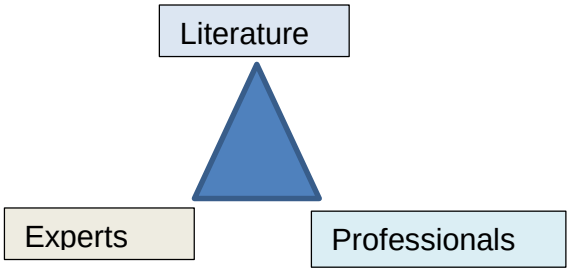

Figure 8 Triangulation of Major Themes

Source: Author's own

6.4.1 Outcomes for success of SIs

The experts and professionals agreed that having SIs in place for mining companies served to protect people and the environment. They agreed that mining companies needed to meet their ESG requirements to impress investors and ensure that their social licence to operate was maintained with ethical investment practices. The literature did not contradict this experience but was more specific in highlighting aspects such as the ESG requirement to meet South Africa's listing requirements on the JSE (Janse van Rensburg et al., 2019).

The experts noted that transparency and sharing of data is an outcome for success of SIs in the mining industry which aligned with the professionals and the literature. The learning from the literature is that mining companies need to have formal stakeholder integration strategies (Juntunen et al,. 2019) that would guide a success with SIs intended to sustain a healthy life for employees and communities.

6.4.2 Critical factors for success

The experts and professionals noted that good leadership in general is a critical success factor in developing and implementing SIs for I&T. The literature added that leadership is essential especially in recognising the value of social indicators (Reid &

Rout, 2020) to build trust and address conflict between mines and communities, with government and political leadership support (King, 2016).

The participants' critical factors included the importance of understanding the risk management while the literature notes that highest risks must be given priority. The literature also added to the professionals experience on circular economy and highlighted the link between digitisation and the circular economy (Okorie et al., 2018)..

The professionals' cost-benefit analysis and in the literature was far more comprehensive in the literature. The literature covered the critical factors of having a reduced number of measurements to make it useful, the development of SIs through cost-effective methods, and the benefits needed to outweigh the technology selection cost (Chong et al., 2016). The need for innovative idea generation tools was covered by professionals and having the right skilled people to use technology effectively.

Critical factors discussed by the professionals on I&T outcomes for success mainly focused on having digital technologies for: effective and efficient monitoring of SIs, measuring SIs, use of drone technology, remote sensing of data, predictive modelling, real-time information, use of AI for data management, wireless systems, the Internet of Things (IoT) and having the relevant infrastructure, hardware and equipment to support implementation.

The literature further supported the critical factors and added that automation requires a skilled workforce. The use of AI was mentioned differently than the professionals to analyse CEO sentiment within annual reports for the credibility of reporting (Na et al., 2020). . The digital twin technology is highlighted to measure past and predict future impacts using SIs (Shvedina, 2020).

The social aspects highlighted by the professionals and the literature is the need for partnerships (King, 2016) and collaboration in developing meaningful SIs that support community interests . A key aspect is identifying and recognizing the cultural values held by communities (Gomes et al., 2015). The literature highlights potential SIs for protecting cultural heritage and the shortcomings of measurement tools to consider the complexities of stakeholder cultural values in the mining industry (Govindan, 2015).

6.4.3 Challenges of SIs for I&T

The challenges of measuring social indicators was shared by the professionals, experts and the literature. The literature added that current SIs dilute the complexity of real social issues (Shvedina, 2020), and getting agreement on SIs within communities is difficult to achieve. The professionals noted that articulating stakeholder value is a necessity within the industry, and the literature noted that stakeholder value can be realised during the participation of diverse stakeholders that can influence the type and quality of the indicator that is being developed (Rinne et al., 2013).

The additional challenges are in mining companies reporting transparently against SIs which is acknowledged by the professionals, and the hindering nature of managers within the mining that prevented transparent reporting was mentioned in the literature (Boiral & Henri, 2017). Another challenge is in integrity of measurements of impacts and consequences to inform the development of SIs.

The professionals' key point is the use of the theory of change to identify and develop SIs for mitigating and managing impacts. Lastly, the professionals, experts and literature agreed that data quality reported to stakeholders need to show preventative measures of leading indicators and disaggregate data to show site level SI performance.

6.4.4 Opportunities

The focus on planetary boundaries was common between professionals and experts as well as carbon neutrality, and the literature highlighted a carbon footprint indicator. The opportunity for more human-centered SIs rather than a I&T driven without considering human impacts was discussed by participants. An additional opportunity mentioned was for a shared ownership model indicator that could indicate the mining performance after closure or automation initiatives.

6.4.5 Summary of similarities and differences

The comparison between the professionals, experts and literature indicate more similarities than differences in the experiences of these three sources of information. The main conclusions will be discussed in Chapter 7.

Table 12 Summary of similarities and differences

*Findings similar to literature; *Findings different from literature*

Outcomes for success	Critical factors to success	Challenges	Opportunities
• manage environmental and social impacts • ESG compliance for shareholders, investor and society • ESG disclosure maintains social licences to operate • Need for ethical investments is growing • SIs are intended to improve and sustain the quality of life • Reporting transparently	• Risk management • Circular economy • Cost verse benefits • Employees data literacy • Digital data systems/platforms • collaboration through partnerships • *Mining departments to integrate SI work • *implicit social contracts • *Organisational culture & community culture • *Leadership - Ability to implement, fail and improve	• Communication of stakeholder value • holding leaders to account for SI performance • no site level data • transparency of reporting • difficult to measure social SIs • *Cannot measure the “honey pot effect” • *Manage individual impacts via theory of change • *gradual impacts realised at mine closure	• Aim for carbon-neutral mines • human-centered approach rather than I&T • Opportunity for a future planetary boundaries indicator • *SIs for benefits beyond closure • *Shared beneficial model to transition communities into a service sector economy

6.5 Conceptual to Final Framework

In this section, the key insights from the discussion in research question 1, 2 and 3 are crystallised into a final framework in Figure 9. The final framework is concluded in Chapter 7. The key insights are discussed as part of the final framework.

Figure 9 Framework with Key insights

Source: Authors own

*Findings similar to literature; *Findings different from literature*

Outcomes for success	Critical factors to success	Challenges	Opportunities
• manage environmental and social impacts • ESG compliance for shareholders, investor and society • ESG disclosure maintains social licences to operate • Need for ethical investments is growing • SIs are intended to improve and sustain the quality of life • Reporting transparently	• Risk management • Circular economy • Cost verse benefits • Employees data literacy • Digital data systems/platforms • collaboration through partnerships • *Mining departments to integrate SI work • *implicit social contracts • *Organisational culture & community culture • *Leadership - Ability to implement, fail and improve	• Communication of stakeholder value • holding leaders to account for SI performance • no site level data • transparency of reporting • difficult to measure social SIs • *Cannot measure the "honey pot effect" • *Manage individual impacts via theory of change • *gradual impacts realised at mine closure	• Aim for carbon-neutral mines • human-centered approach rather than I&T • Opportunity for a future planetary boundaries indicator • *SIs for benefits beyond closure • *Shared beneficial model to transition communities into a service sector economy

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This chapter concludes this study and presents the contributions made in the research. The main conclusions will be briefly discussed, and the sections to follow are the research contribution and the implications for management and other stakeholders. The last sections present the limitations and recommendations for further research that can be pursued to refine this study.

7.2 Development of the Final Framework for SIs for I&T

The final framework is presented that depicts the integration of the 4 constructs of: what success looks like for SIs for I&T; the critical factors in achieving this success; challenges and opportunities of SIs for I&T.

The framework's components are informed by the Chapter 2 literature review, the Chapter 5 findings, and the Chapter 6 discussion. This chapter's conclusions are the key insights and findings emanating from the similarities and potential differences against the framework.

7.2 Main conclusions

a) Success with SIs and I&T

The key insights for success with SIs for I&T were focused on managing environmental and social impacts at a local and global level, for the protection of people and the ecology, climate and water aspects. Govindan, (2015) highlights that implementation of a successful strategy for SIs include enhanced environmental management and cleaners technologies (Govindan, 2015) that can be applicable at a global level; while local issues such as waste management where mines are located close to communities also impact the quality of life (Chong et al., 2016).

Batterman (2017) is supportive of responsibility towards the environment and society by mining companies (Batterham, 2017) which will ultimately improve the quality of life for people living around the mine. The quality of life indicators includes SIs for health

and safety, and is directed at keeping employees working safely and preventing any health impacts at both a physical and mental level (Ranängen & Lindman, 2017).

Success of SIs is also intended to comply with ESG requirements to ensure that mining sectors satisfy and report against the information investors could use to analyse company SI performance (Janse van Rensburg, 2019). The ESG requirements are self-regulation of the company to act transparently (Ranängen & Lindman, 2017) and supports ethical investment practices.

An outcome of success on the disclosure of ESG information is to maintain the company's social license to operate and establish credibility as a transparent business (Talbot & Barbat, 2020).

b) Critical Factors for success

Critical insight on risk management is the need to know the SI risks. This can be done by assessing SI data that shows trends and patterns to assess the costs and benefits of SIs over time (Santana-Medina et al., 2013). SIs reflect what is happening in the social context considering the interests and views of stakeholders (Santana-Medina et al., 2013) and hence the cost-benefit analysis of SIs for I&T can benefit all stakeholders. The SI's need to be clear, concise, and measurable needs to show trends and patterns of data to assess the costs and benefits over time (Santana-Medina et al., 2013). An essential feature of cost of SIs is that SIs are more likely to be implemented if the cost of implementation was realistic for the impact being managed (Bui et al., 2017).

Data-driven digital tools and platforms were of critical importance to achieve success with SIs for I&T, mainly to allow leaders to make decisions based on useful data. This included a myriad of new technologies and innovation noted as critical to the success of SIs for I&T:

- remote monitoring and analyses of data at inaccessible locations where remote sensing can be used (Shvedina, 2020) example via drone technology;
- real-time information provides immediate results, enables understanding immediate impacts and predicts future scenarios (Cisco, 2016);

- use of robotic automation in a technology strategy (Shvedina, 2020);
- automation to transition to Industry 4.0 (Okorie et al., 2018) with automation reducing negative environmental impacts but can lead to job losses;
- monitor pollution through automated pollution monitoring systems (Shvedina, 2020);
- use of AI to analyse Chief Executive Officer's (CEOs) sentiment in mining sustainability reports against a sustainability balanced scorecard (Na et al., 2020).

Of critical importance is having the physical infrastructure to implement these technologies to ensure continuity of the systems (Shvedina, 2020). This needs to be supported and managed by employees who are knowledgeable and capable of implementing technology; and the workforce needs to be skilled and trained in digital technologies and related software and hardware that is planned for use on the mine (Shvedina, 2020).

A potential refinement to the literature is in the ability of leadership in mining to implement SIs for I&T, fail in this implementation and then learn and improve from it. Leadership is essential to make people feel included, foster collaboration, and support equality (Hale et al., 2019).

The implicit social contracts that a mine has with the community is also a potential refinement to the literature. The implicit or unspoken contract holds mines accountable for developing mutually beneficial SI outcomes with communities. Santana-Medina et al. (2013) notes that a participatory approach in developing SIs is fundamental in communities living in protected areas with inherent value (Santana-Medina et al., 2013). The benefits can be realised in transparent agreements with stakeholders such as communities that are impacted (Gomes et al., 2015).

Another potential refinement is the need to align organisational culture with an awareness of community culture. The mining organisational culture needs to have an awareness of community cultural aspects and how it can impact communities' cultural values.

The current measurement tools available for SIs fails to consider the complexities within the mining sector such as cultural values of stakeholders (Govindan, 2015); and Reid & Rout (2020) highlight the importance of cultural values to decision making (Reid & Rout, 2020) which must be considered by mining leaders.

c) Challenges

The key insights on challenges in identifying, developing, and using SIs for I&T have shown that undertaking participatory processes with stakeholders in developing indicators is a challenge (Santana-Medina et al., 2013). There is also a lag in reporting real-time data for decision making with the added complication of aggregated data (Sardain et al., 2016) that does not show site-level SI performance. There is a challenge in mining sectors reporting data transparently with social indicators being particularly difficult to measure accurately (Chong et al., 2016).

The literature challenges appear to place greater importance on quality of life at ensuring stakeholders have their basic needs met, and the overall quality of life is improved (Suopajärvi et al., 2016). It describes value judgments in developing social indicators for the importance of sustainability measurements, decision-making, and cultural values (Reid & Rout, 2020).

The literature's potential refinements are the difficulty in measuring the “honey pot effect” where people gravitate toward the mine that provides the most community benefits. This relates to the social sustainability indicators currently that are too simple and dilute the complexity of real social issues (Hale et al., 2019).

A potential refinement to the literature is also the management of sustainability impacts at an individual level through a theory of change. The last potential refinement under challenges is that mining companies' impacts happen gradually and the full impact is only realised at mine closure. The concept of full impact decision-making can support this when the participatory approaches of developing and implementing SIs are followed (Santana-Medina et al., 2013). This includes local context and knowledge of

communities and gives communities the chance to benefit from inclusion in decision making (Santana-Medina et al., 2013).

d)Opportunities

The key insights on the opportunities for SIs for I&T is the development of carbon-neutral indicators, and indicators that support the balance between planetary boundaries as well as human-centered SIs. Some human-focused indicators are related to labour and employment, occupational health and safety, training, education, diversity and equal opportunity, and equal remuneration for women and men (Arthur et al., 2017).

A potential refinement of the literature is the shared ownership/beneficial models where communities can benefit from implementing technology such as automation by transitioning to the service sector model, which then provides long-term benefits after mine closure.

e)Summary of the main conclusion

The key insights are concluded to show mainly similarities with the literature reviewed. The refinements are presented in the final framework in Figure 10 and the potential contributions will follow.

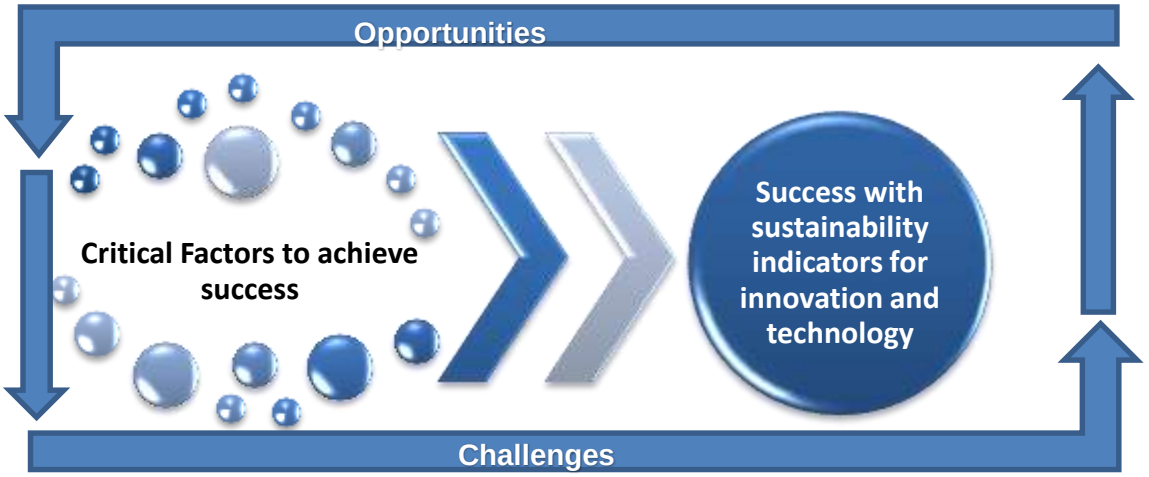

Figure 10 SI for I&T Framework (SIIT)

Source: Author's own

Outcomes for success	Critical factors to success	Challenges	Opportunities
Only similarities with the literature, no potential refinements • manage environmental and social impacts • ESG compliance for ethical investments • SIs are intended to improve and sustain the quality of life • Reporting transparently	*Potential refinements* • Implicit social contracts • Organisational culture & community culture • Leadership - Ability to implement, fail and improve	*Potential refinements* • Cannot measure the "honey pot effect" • Manage individual impacts via theory of change • Gradual impacts only realised at mine closure	*Potential refinements* • SIs for benefits beyond closure • Shared beneficial model to transition communities into a service sector economy

7.3 Potential Contribution

The contributions of the research are discussed in this section.

a) Outcomes for success

The potential contribution to the outcomes for having SIs for I&T is in similarity to the literature. The similarity is closely aligned with compliance with ESG performance requirements and protecting people and the environment. Success is expected if there are transparency and sharing of data by mining companies.

b) Critical factors

The potential contribution is in a potential refinement to a challenge faced by leaders in mining sectors. It seems that leaders cannot implement SIs for I&T, fail in this implementation and then learn and improve from it.

The challenge of implicit social contacts with communities is the unspoken contract for mutually beneficial outcomes with the mine. A potential contribution is the possible refinement of the literature for implicit social contracts between mining sectors and communities.

A potential contribution is the need to potentially refine the literature on the alignment of organisational culture with an awareness of community cultures impacted by mining. This alignment may prevent any cultural misunderstandings and incidents.

c) Challenges

The potential contribution is a potential refinement of the literature on sustainability impacts happening gradually with the full impact only realised at mine closure.

Additionally, the potential contribution to another potential refinement in the literature is the difficulty in measuring the “honey pot effect” where people gravitate toward the mine that provides the most community benefits.

Lastly, the potential contribution to a potential refinement is the management of sustainability impacts at an individual level through a theory of change concept.

d) Opportunities

The potential contribution is the potential refinement of the literature on the shared ownership/beneficial models where communities can benefit from the implementation of technology such as automation by transitioning to the service sector model, providing long-term benefits after mine closure.

7.4 Implications for management and other relevant stakeholders

The final framework developed in Figure 10 provides managers with more guidance, a better understanding, and greater awareness of SIs for I&T in the mining sectors. The specific areas that would be valuable to a manager are that SI and I&T success is experienced as the mining sector meeting and complying with ESG requirements. When people and the environment are protected, this is viewed as mining companies being strong sustainability performers. The key is being transparent with ESG as well as environmental social and economic performance reporting. The refinements of the literature are valuable for managers and are summarised as:

- The successful implementation of SIs for I&T depends on courageous leaders who can implement SIs for I&T, fail in this implementation and then learn and improve. Managers need to undertake SIs for I&T with the confidence that failing implies learning;
- The challenge of implicit social contacts with communities is the unspoken contract for mutually beneficial outcomes with the mine, and managers need to know what the implicit social contract is with their local communities. The implicit social contracts will be specific to the communities, and the cultural values held. This ties in with the need to align organisational culture with the awareness of community cultures impacted by mining. This alignment will prevent any cultural misunderstandings and incidents.
- Managers also need to plan and strategize on mitigating long-term impacts that happen gradually, and the full impact is realised at mine closure. This mine closure planning and foresight will support phased mitigation of impacts that will prevent irreversible damages.

- The “honey pot effect” of people gravitating towards the mine will determine what SIs can be put in place to measure SI benefits. Social benefits must be well thought out to ensure it add the value intended by the mine;
- The theory of change is mentioned as involving the management of sustainability impacts at an individual level. This is closely related to a manager's impact and control strategies that should consider new progressive strategies such as change theories.
- In the future, the shared ownership/beneficial models would be a solution to technology and innovation advancements in mining where communities can benefit from the implementation of technology such as automation by transitioning to the service sector model, which then provides long terms benefits after mine closure

7.5 Limitations

The first study limitations are covered in Chapter 4 under the methodology section. The following additional limitations are noted for this study:

- The mining commodities that were scoped into this study did not seem to produce commodity-specific results, and this may be a limitation in the types of mining commodities covered across the geography selected;
- The literature reviewed may not have covered all current knowledge on the extensive literature for sustainability, SIs, and I&T to confirm the potential contributions and potential refinements. Specifically, the following was not covered in-depth :
    - The challenges on the implicit social contacts between a mine and communities for mutually beneficial outcomes;
    - The alignment of organisational culture with an awareness of community culture;
    - The mitigation of long term impacts for full impact management at mine closure;
    - The “honey pot effect” or the future of social indicators;
    - The theory of change for management of sustainability impacts at an individual level;

- shared ownership/beneficial models with communities to benefit from solutions to technology and innovation advancements

7.6 Suggestions for future research

The possible areas of future research are in the potential refinements found in the results of this study. There are summarised further as future research on:

- how much success depends on mining sector leadership having the ability to implementing SIs for I&T, fail, and then learn and improve from it;
- challenges of implicit social contacts with communities as the unspoken contract for mutually beneficial outcomes;
- alignment of organisational culture with the awareness of community cultures impacted by mining for the prevention of cultural misunderstandings and incidents;
- mitigating long term impacts that happen gradually and the full impact is realised at mine closure;
- what the “honey pot effect” implies for the future of social indicators;
- the theory of change for management of sustainability impacts at an individual level;
- shared ownership/beneficial models for the solution to technology and innovation advancements in mining where communities can benefit from the implementation of technology such as automation by transitioning to service sector model;
- the study could be undertaken using different or additional commodities with participants from other locations

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Appendix A

Codes: Professionals

Codes
ability to articulate sustainability
access remote locations
access to data
AI spots patterns
align environmental and social
anticipate social issues
apply risk management processes
apply systems thinking
appropriate infrastructure required
articulate business case
articulate stakeholder value perspective
assess complexity of situations
assess value of technology
attract investors with sustainability
attracts employees seeking purpose
automation
avoid costly delays
avoid duplication of SIs
avoid honey pot effect
avoid impact at individual level
avoidance process for risk
avoiding future liabilities
balance qualitative and quantitative
balance society and legal
based on local trends
being carbon neutral
benchmark competitors
benchmark health indicators
benefits communities
beyond closure planning
beyond financial performance
bio-mimickry principles
build towards an outcome
Build value framework
building new business models
Business sustainable costing models
can avoid reputational risk
cannot monitor values beliefs

cannot value values
capacity to absorb change
Change management process
changes a non-mechanised workforce
circular economy
Clarify technology aims
clean power sources
clear accountability for delivery
Clear message from leaders
clear message to communities
Clear narrative on sustainable value
combine technologies step change
commonality in measurements
Communication internal external
Communication of indicators intent
communities not homogenous
community investments
comparable to competitors
compare aggragated data
consider life of asset
consistent monitoring & reporting
consumer led demands
continous improvement
contractor managment
contributes to overall sustainability
correct systems in place
cost benefit analysis
cost benefit methodology
Cost effective solution
Covid fosters change
Covid mental health indicators
Covid response furloughing staff
create enabling idea platforms
cumulative benefit of technology
dashboard of indicators
data available on website
data driven decisions
data forecasting
data literacy of people
data needs defined
Data policy needed
data puddle ponds lakes approach
data sets identify problems
define individual controls

Define KPI's
delivery context specific
delivery site specific
Demand sustainable products
demonstrate need for changes
demonstrate value reporting
Design indicator correctly first
Design sustainability into technology
desire short terms results
determine appropriate technology
develop proactive plans
developing value chain partners
different people different views
different way of reporting
differential outcome business level
differential outcome community level
digital preparedness
digital technology mix indicators
digitally driven indicators
donnot accept mediocre performance
Donot need more indicators
donot need new indicators
donot represent local community
driven by reward structures
drought management
Easier to quantify biodiversity
Easier to quantify carbon
Easier to quantify water
ecological protection
ecthical investment funding
employee brand loyalty measurement
employee sentiment
enable decision making ability
enhancement of processes
environmental and social benefits overlooked
ESG value driven
ethos of sustainability engrained
evaluate costs environmental social
evolving trends
Extend beyond NPV
external context is dynamic
external expectation of ethical practice
extract method to define value

fit for purpose
fulfill social contracts
full impact decision making
good news culture
GRI produces statistics only
having right values systems
Health systems for wellbeing
healthy life years lived
high digital literacy
how to change perceptions
how to cost worsening a life
human centered approach irreplaceable
hydrogen trucks
identify opportunities environmental social
immediacy of metrics
impact reduction
implicit explicit contracts exist
implicit prosperity post mining
improve data quality
inclusive participation all stakeholders
Indicator for avoiding negative
informed levels of technology
innovate for social purpose
Innovation saves time
intergrate flows of economy
Intergrate stakeholder expectations
intergrated approach internally
Internet of things enabler
invest for social inclusion
investors need few indicators
keep information simple
key challenges evironmental and social
Know assumptions
Know process inputs and outputs
Leadership commitment
leadership culture transformation
leaving a positive legacy
link data and technlogy
livelihood skills planning
living mine vision
localised decentralised mass action

make intervention-based changes
manage automization processes
manage on the ground
Managing Risk
mapping problems with solutions
measure outcomes
measure year on year improvement
Measurement metrics already available
measures degree of change
measures social acceptance
measuring inert material impacts
metrics on educational outcomes
metrics on health status
Mindset change to zero impacts
more transparency
Motivate through performance bonuses
move to continual reporting
mutual beneficial outcomes
need practical targets
need regional indicators
Need resources skills money
Need sustainability value model
need systemic change
net positive biodiversity impact
new technology - Floatation bulk sorting
no consistent approach
no fatalities no injuries
Not aware of any SIs for I&T
Not just financial benefits
not meaningful negative results
NPV driven
obtain community consent
offer services not products
old technology not safe
online digital service platforms
Organisation culture critical
partnerships
people working from home
permitting new technology
Permitting solutions
pilot technology before upscaling

planetary boundry protection
positive impacts of technology
predictive approach
predictive monitoring
proactive decision making
process changes
qualitative and quantitative benefits
quantify social values sentiments
real time data decisions
real time monitoring
real-time reporting creates transparency
redesigning wholistic approach
reduce footprint
reduction in water GHG energy
regulator support of initiatives
rehabilitate your mindset
remote data collection
remote sensing
remote sensing capabilities
report on contribution to society
report technological positive disruption
reporting can improve
reporting on innovation
Reporting to stakeholders
reporting transparently
reputation marketing
responsibility cuts across disciplines
responsibility for shaping demographics
responsibility outside fence
right message from leaders
right organisational culture
right political leadership
rigid reporting structure
robust understanding of external factors
Robust methods of evaluation
robust monitoring and evaluation
safety wearables practical use
Saftey impacts unacceptable
Saftey systems checks
scrap closure
SDG's understanding

Seek risks and opportunities
senior management commitment
service sector focused economy
share knowledge with communities
Shared beneficial models
shared ownership models
shifting towards something unknown
SIs not intergrated
SI's used poorly
Slow pace of change
social is long term results
social licence to operate
Social responsibility Investors
social take people with
Solution testing opportunities
speed of implementation increasing
spiritual considerations in funding
strategy and risk assessment
suite of meaningful indicators
Sustainability impacts unacceptable
sustainability is everyones responsibility
sustainability value framework needed
sustainability values for decision making
sustainable energy water sources
system induced trigger actions
tackle global environmental issues
tangible measurement of social elements
target ecological succession
target entire systems solutions
technology bio-mimickery hydrogen
Technology exists not used
technology fosters change
Technology generate value
technology improves impacts
Technology is mutually benefical
Technology systems not intergrated
test rigour of indicator
Theory of change
Tie indicators to site level
time lag on data driven decisions
time management for productivity

topic dominating boardrooms
track performance
tracking targets goals
transition to automization
transition to green economy
transparency of mining sectors
trust of company by community
trusted corporate leader
understand context of problem
understand data landscape
understanding sources of risk
use digital technology
use local knowledge
use substitute products
value chain management
wicked problem solving needed
work collaboratively
younger people for solutions

Categories: Professionals

Categories
SI intended to manage social and environmental impacts (carbon emissions, water, biodiversity)
Need to measure the consequences of impacts
Make decisions based on understanding full impacts
Technology saves money by eliminating impacts
Don't have an indicator to avoid negative impacts
Technology needs to reduce impact footprints
Need for mindset change to no zero negative impacts, like safety has
Innovation technology outcomes must be real-time, predictive, automated and digitised
Opportunities in automation and digitisation
Take a predictive approach to measuring indicators
Depends on digital preparedness and connectivity
Measure through enablers like the internet of things/digital technology mix
Opportunities in automation and digitisation
Technology implementation dependant on employee digital literacy
Technology leads to mechanised workforce
Outcome of SI I&T is a circular economy
A circular economy is the answer
SI intended to manage carbon emissions
Future is carbon neutral

Need to measure the consequences of impacts
Measure with systems thinking and theory of change
Measure through enablers like the internet of things/digital technology mix
SI's cannot measure change in perceptions
SI's cannot measure quality of life and deterioration
Indicators measure the degree of change
Measure SI through local knowledge of communities
Measure sustainable water and energy indicators
Financial value can be measured through investors
SI used to measure social acceptance
Challenges with poor data quality for decision making
Success depends on data driven decisions
Need for proactive decision making
Problem of time lag on data for decision making
SI enables decision making
Need for measurable cost-benefit analysis of the indicators
Technology can save costs
Need resources and funding for new technology
Satisfy investors shareholders for ethical investment funding
Investigate the risks and opportunities for technology integration into sustainability.
SI in place to invest in communities

Financial value can be measured through investors
Mining needs a clear narrative of sustainability value when reporting externally
Reporting on SI creates transparency
Need for continual reporting verse annual
Poor quality of reporting against SI's
Reporting of SI can improve
SI's meet reporting obligations
Clear message from leaders to communities
Must have leadership commitment to work
Technology implementation needs right political leadership
Technology must benefit employees and communities
Clear message from leaders to communities
Must have leadership commitment to work
SI used to create trust by communities toward the mine
SI's don't represent local communities
SI's cannot show quick results within communities
Measure SI through local knowledge of communities
SI intended to obtain community consent
The intent of the SI must be well communicated
SI in place to invest in communities
Mining is ESG value driven /reputation
Need for an integrated approach to implementing SI's
Need to permit for implementation of SI Tech and Innovation

Technology implementation dependant on employee digital literacy
Technology implementation needs change management
Technology implementation needs right political leadership
Must have partnerships to implement SI Tech/Inn
Critical to consider the theory of change for successful implementation
Be able to absorb change when implementing SI's
Implementation needs localised decentralised action
Shared ownership models for SI success
Clear accountability of employees to deliver success
Success depends on defining KPI's
Understand the data landscape for success with data management
Use leading not lagging SI's for success
SI intended to manage social and environmental impacts (carbon emissions, water, biodiversity)
Innovation needs to have social purpose
Si's used to balance social and legal compliance
Not easy to anticipate social issues
Mining needs to maintain its social license to operate
SI used to measure social acceptance
Keep high performing employees with right value systems
Create dashboard of indicators to view performance
Sustainability performance driven by employee reward stuctures

SI's help to continuously improve performance
Opportunity to develop a company values indicator
Mining needs a clear narrative of sustainability value when reporting externally
Keep high performing employees with right value systems
Be able to articulate stakeholder value to get support for SI's
SI's cannot monitor values and beliefs
SI aimed at value chain management
Will be more focus on cultural values
Financial value can be measured through investors
Mine closure will not exist in future
Human-centered approach will be the future of SI
The future of sustainability is unknown
The future is developing responsible supply chains
Future is real-time monitoring and data collection
Innovation technology outcomes must be real-time, predictive, automated and digitised
Create enabling platforms for technology & innovation ideas
Innovation needs to have social purpose
Create enabling platforms for technology & innovation ideas
Need for innovation to be practical for use like safety gear
Innovation saves time
Consider partnerships when developing indicators
Must have inclusive partnerships with all stakeholders

Must have partnerships to implement SI Tech/Inn
Investigate the risks and opportunities for technology integration into sustainability.
Need for a reputation risk indicator
SI in place to manage risks
Apply a risk management processes to determine impacts
SI's sustain a healthy life through planetary boundary protection
SI's manage health impacts
Opportunity for a mental health indicator after Covid

Codes: Experts

Codes : Experts
ability to implement, fail and improve
awareness of climate change
reputational awareness repercussions of contamination
big gap between social/economic issues
breadth of knowledge of team
change mine processes
closure planning
commitments -responsible mining index
mine modernisation
companies do the minimum
costs of innovation
developing meaningful qualitative indicators
different processes link seen in SD reports
disaggregation of data to show site level
Economics driving renewable energy, solar and wind
employee wellness and happiness indicators
ensuring technology is mature and good quality
ESG financial decisions and operational decisions
ESG will determine share price
full impact realised at closure
funding required
have been changes in thinking about I&T
how we work health and safety
Identify technologies today for 2050
indicators don't measure the right things
Indicators lead to change or decision making

indicators only good as the data its supplied
Indicators set by sustainability experts only
Indicators that are voices and perspectives of communities
Indicators that are voices and perspectives of communities
know your competitors capability for technology
knowing boundaries and product
Limited bigger picture thinkers
Linking social and environmental issues
look at new business development
manage or clean water resources better
manage risk of mining collapses of tailings dams
Mature verses no use
measuring is longer term measuring,
More repeated communication
Nexus of indicators grouped together
Non-financial risk are real operational risks
Non-financial risks addressed at board level
Not knowing the right indicators
Not sure what the indicators used for SD I&T currently
number of complaints or grievances
number of whistle-blowers anonymous responses
Opportunities arise as society progresses
Opportunities for new markets
Policies and procedures not adequate controls
Poor quality huge disruptor
potential job losses
pre-implementation, implementation checks
R&D opportunities outside SD
report for Stock Exchange and investors

research and development to drive improvements
responsible mining index supports indicator development
Right people to implement
Right resources on the ground
rolled out correctly
rule book is more stringent and sophisticated
senior leadership buy in and support for
Shaped by what the world looks like in 2050
Shareholder activism
Shareholders and communities focus on wrong stuff
show the interconnectedness of indicators
Site level data not reported externally for indicators
social indicators key in pandemic
Some issues cannot be measured like social issues
stakeholders sharing of data
stay on top of your R&D and innovation
support with budget
Sustainability of life on this planet
Sustaining planetary boundaries
talk about delivery and output in reports
Technology is analytical layer to interpret the data
thinking bigger picture and longer term
Top decision maker to understand indicators
trying to understand your local context and issues
understand the financials
Understand value of these indicators
Use standardized indicators in one system
visionary leadership

wellbeing of workers employees communities

Categories*: Experts*

Categories
Leadership required for SI implementation
Poor quality of data/indicators is a challenge
Know the cost benefits of SI's and I&T
Need to determine social measurements metrics
SI's in place to protect mines reputation/ESG
Need to think big picture and longer term/planetary boundary
Knowing risks will drive decisions/ESG
Solve by taking effective action/ESG
Must understand who are the experts setting the SI's for I&T
SI's for I&T are not used or known
ESG is the ultimate goal of SI's
Must understand SI's used for meeting commitments verse getting value
SI's are currently used in reporting
Must keep abreast of research trends to improve
Need proper change management for implementation
SI's can be used to change mine processes
Mines need to understand competitors I&T capabilities
Health and Safety is an outcome of I&T
Solve SI issues by listening to communities
social indicators key in pandemic
Can have job losses with I&T
Need mines to show interconnectedness of SI's
Need to know the boundaries of SI application
Limited big picture thinkers in mining
big gap between social and environmental indicators
Identify technologies today for year 2050

Don’t have proper change management for implementation
Technology is a tool for data interpretation
Need meaningful qualitative indicators
Must understand financial costs
R&D must be used for innovation
Mine closure planning is required
Full impact is known at mine closure
Cannot measure social impacts
Water resource management will become more important
Research and Development is an outcome of I&T
Future is shareholder data management
SI's serve to manage impacts
Need employee wellness and happiness indicator
ESG will determine investments and share price
Future depends on stakeholders sharing data

Appendix B

Ethics Approval

Ethical Clearance Approved

Dear Nishi Hariparsad,

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

Appendix C

Recruitment email for an interview:

Dear Interviewee

I trust that you are doing well?

I am currently a student at the University of Pretoria's Gordon Institute of Business Science and completing my research in partial fulfilment of an MBA.

I am conducting research on sustainability and I am trying to find out more about sustainability indicators for innovation and technology in the mining sector. This email is a request for a personal interview to draw from your experience in my field of study.

The purpose of the interview is to gain an understanding of how you have experienced sustainability (in the environmental, social or economic areas) in relation to innovation and technology. I am focusing on the mining sectors of Platinum, Gold, Copper, Iron Ore, Diamonds, Nickel and Coal and not on a specific company.

The interview is expected to last for an hour using Microsoft Teams. There is no need for preparation for this interview, as I am solely interested in your personal experiences. Please let me know if you are able to participant and I can schedule this at your earliest convenience.

I look forward to hearing from you.

Regards Nishi

INTERVIEW PROTOCOL

INTERVIEW 1: Sustainability Professionals

Exploring sustainability indicators for innovation and technology in mining

INTRODUCTION AND WELCOME

Thank you for agreeing to participate in this study about sustainability indicators for innovation and technology. My study is about exploring these indicators for innovation and technology specifically in the mining sectors of Platinum, Gold, Copper, Iron Ore, Diamonds, Nickel and Coal. I am interested in your experiences with sustainability indicators in these mining sectors.

To Note: The student will send the informed consent form electronically to the participant once they have agreed to participate in the interview. If this is not possible, then the student will present the informed consent form to the participant at the start of the interview. The participant is given time to read the form and ask any questions. The participant will be asked to sign the form before proceeding with the interview.

INTRODUCTORY QUESTION 1: To start our interview, please tell me about how you got involved in the sustainability field?

QUESTION 2:

Part 2a: Please tell me about what the expected outcomes are of having sustainability indicators in the mining sector?

Part 2b: Having explained the above outcomes, are there any outcomes specific to innovation and technology?

QUESTION 3: What are the critical factors and/or indicators that need to in place in order for you to achieve success with these innovation and technology outcomes?

QUESTION 4: In our experience how are sustainability indicators for innovation and technology used in the mining industry?

QUESTION 5:

Part 5a: Please tell me about how you deal with the challenges experienced in using sustainability indicators for innovation and technology in the mining sector?

Part 5b: How do you overcome those challenges?

QUESTION 6: Please describe the opportunities you see for developing new sustainability indicators for innovation and technology in the mining sector?

QUESTION 7: How would you measure the outcomes that you have expressed for innovation and technology to assess whether or not these outcomes are being met or not?

CLOSING QUESTION 8: Looking forward, how do you see this developing over time?

Probing questions

- Could you tell me more about that?
- Could give me an example of that?
- Tell me more about that project?
- Could you tell me what happened?

Clarification questions

- Could you clarify that term/word/acronym?

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INTERVIEW PROTOCOL

INTERVIEW 2: Sustainability Experts

Exploring sustainability indicators for innovation and technology in mining

INTRODUCTION AND WELCOME

Thank you for agreeing to participate in this study about sustainability indicators for innovation and technology. My study is about exploring these indicators for innovation and technology specifically in the mining sectors of Platinum, Gold, Copper, Iron Ore, Diamonds, Nickel and Coal. I am interested in your expert opinion with sustainability indicators in these mining sectors.

To Note: The student will send the informed consent form electronically to the participant once they have agreed to participate in the interview. If this is not possible, then the student will present the informed consent form to the participant at the start of the interview. The participant is given time to read the form and ask any questions. The participant will be asked to sign the form before proceeding with the interview.

INTRODUCTORY QUESTION 1: To start our interview, please tell me about how you got involved in the sustainability field?

QUESTION 2:

Part 2a: Please tell me about what the expected outcomes are of having sustainability indicators in the mining sector?

Part 2b: Having explained the above outcomes, are there any outcomes specific to innovation and technology?

QUESTION 3: What are the critical factors and/or indicators that need to in place in order for you to achieve success with these innovation and technology outcomes?

QUESTION 4: In our expert opinion how are sustainability indicators for innovation and technology used in the mining industry?

QUESTION 5:

Part 5a: Please tell me about your expert opinion on how the challenges experienced in using sustainability indicators for innovation and technology in the mining sector should be dealt with?

Part 5b: How do you overcome those challenges?

QUESTION 6: Please describe the opportunities you see for developing new sustainability indicators for innovation and technology in the mining sector?

QUESTION 7: How would you measure the outcomes that you have expressed for innovation and technology to assess whether or not these outcomes are being met or not?

CLOSING QUESTION 8: Looking forward, how do you see this developing over time?

Probing questions

- Could you tell me more about that?
- Could give me an example of that?
- Tell me more about that project?
- Could you tell me what happened?

Clarification questions

- Could you clarify that term/word/acronym?

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