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Investigation of social, environmental and financial impacts of energy supply interruptions in Richards Bay smelter

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

Johannesburg, February 2025

ABSTRACT

Energy supply disruptions are posing an ever-greater threat to energy-intensive sectors, especially those like smelting, which depend on an uninterrupted flow of power to keep their operations running. Energy interruptions at the Richards Bay Smelter potentially have serious consequences socially, environmentally, and financially. This is due not only to the importance of the smelter for the local and national economy but also to the large number of people it employs.

Three main goals guided this study: first, to figure out how power cuts impact the smelter socially, environmentally, and financially; second, to investigate and assess how effective current mitigatory ways of dealing with energy interruptions and third, to propose mitigation measures to address the social, financial and environmental impacts of energy supply interruptions on Richards Bay smelter.

Utilising a mixed-methods approach, the research integrated quantitative data collected from questionnaires with qualitative insights gathered through interviews with 50 senior management professionals at the Richards Bay Smelter. The results enhanced the understanding of the challenges associated with energy disruptions and provided practical recommendations for reducing their negative effects on both the smelter's operations and the surrounding community.

The study established that energy supply disruptions have serious effects on several fronts. From a social perspective, they seem to lead to job losses, financial stress, and a decline in worker morale. From an environmental viewpoint, they result in unplanned emissions and inefficiencies because of interruptions in procedures that are supposed to control pollution. From a financial aspect, energy interruptions entail losses in production, higher operational costs, and a decline in the company's competitive edge. While some mitigation strategies, such as backup power systems and stakeholder collaboration, have proven effective, gaps remain in addressing long-term resilience. The study concludes by recommending enhanced investment in renewable energy integration, strengthening infrastructure resilience, and implementing proactive energy management policies. These recommendations aim to minimise future risks and ensure industrial sustainability amid South Africa’s evolving energy landscape.

KEYWORDS

Energy Supply Interruption

Richards Bay Smelter

Social Impact

Environmental Impact

Financial Impact

Mitigation Measures

Electricity Reliability

Sustainability

DECLARATION

I, **Ntombozuko Willie**, declare that this research report titled, ***Investigation of Social, Environmental and Financial Impact of Energy Supply Interruption in Richards Bay Smelter,*** is my work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in Energy Leadership at the University of the Witwatersrand (WBS), Johannesburg. It has not been submitted previously for any degree or examination at this university or any other.

Name: Ntombozuko Willie Signature: 

Signed at …….Johannesburg…On the ……24. day of …February…… 2025

DEDICATION

I am dedicating this research report to four people who have been supporting and continue to mean so much to me.

First and foremost, my grandmother used to say, “Education is the key to open closed doors”. She was my first mentor. She taught me the most basic things I needed to know, and most of them were and are still important for my life journey. Her influence remains the basis and foundational values I use and live by.

Next, my family, especially my mother Nokulunga Willie, who raised me, loved and taught me all the values, principles of life and encouraged me to be strong, also to never stop learning.

To my children Siyabonga, Nqaba and Wonga, you are always my driving force, for your continued support, patience and contribution while I spent hours studying during this journey. Words are not enough to express how much I love you all.

Lastly, I am dedicating this to my wonderful friends who kept on pushing and encouraging me. Dr Ayanda Ntetha's words are not enough to express my heartfelt appreciation of you all for your love and support.

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Firstly, I acknowledge the Lord for the strength to be who I am today. He has been guiding me throughout this journey.

Thank you to my supervisor, Dr Silas Mulaudzi, for shaping, leading me through this journey and pointing me in the right direction. I couldn't be where I am if you were not my supervisor. I will always remember this: "Go and read, you have a lot of work, we do not have time". For giving so much time in your busy schedule and continuing to give back to others with such passion. Thank you again for believing in me. I cannot forget your mentoring and leadership skills towards me.

I am grateful to all the brilliant minds I have met within the Wits Business School, to find better ways of doing things, every conversation that inspired so many ideas illuminated something new, I found a friend who also motivated me throughout this journey, Ndabenhle Zungu, thank you.

Countless people believed in me and helped me through this journey.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

South Africa has experienced its fair share of energy supply interruptions over the years, which have had a significant impact on energy users, particularly heavy electricity users (Puttamadappa & Parameshachari, 2019). These interruptions, whether due to infrastructure failures or planned load shedding, can have severe social, environmental, and financial implications for industries and businesses that heavily rely on electricity. To mitigate these impacts, the government and the energy sector have put in place measures that will ensure a reliable and stable energy supply for heavy electricity users. Notable measures include the Energy Action Plan, which has been put in place to deal with the problem of load shedding.

The Richards Bay smelter is a crucial part of South Africa's industrial landscape, providing a significant amount of aluminium to various industries and contributing to the country's economy (Msane, 2019). However, the smelter's operations are heavily reliant on the energy supply, which is evidenced by the exemption of the smelter from loadshedding. The smelter, despite being exempted from load-shedding, however, suffers from other energy interruptions in this supply, largely due to faults, and they can have a significant impact on the social, environmental and financial aspects of the region.

This research aims to investigate the consequences of energy supply interruptions in the Richards Bay smelter, with a focus on understanding the social, environmental, and financial implications. The social impact of energy supply interruption in the Richard Bay smelter is significant, as it affects the livelihoods of the employees working in the smelter and the surrounding communities (Bird, von Gruenewaldt & Petzer, 2022).

Energy supply interruptions can lead to temporary closures or reduced production in the smelter, resulting in job losses and decreased income for the employees. This, in

turn, can have a ripple effect on the local economy, leading to increased financial hardship for the community members. Additionally, the social impact extends to the health and well-being of the employees and residents, as reduced production in the smelter may result in increased air pollution and environmental hazards (Makgetla & Patel, 2021).

From an environmental perspective, energy supply interruptions can have severe consequences on the local ecosystem and the surrounding environment (Soltani et al., 2021). The Richard Bay smelter is a significant source of air and water pollution, and any interruption in its operations can lead to a temporary decrease in the release of harmful emissions. However, the prolonged shutdown of the smelter can also have adverse effects on the local environment, as it may disrupt the natural balance and lead to long-term repercussions on the ecosystem and biodiversity of the region.

The financial impact of energy supply interruptions in the Richards Bay smelter is a concern for the stakeholders and the economy at large. The smelter contributes significantly to the country's GDP and relies on a continuous and reliable energy supply for its operations (Makgetla & Patel, 2021). Any interruption in the energy supply can result in significant financial losses for the smelter and its stakeholders, impacting the profitability and sustainability of the business. Moreover, the financial impact extends to the wider economy, as the reduction in production and the potential job losses can lead to decreased economic activity and increased financial strain on the local and national levels (Makgetla & Patel, 2021).

1.2 Purpose of the Study

The study is premised on the need to find what measures can be put in place to mitigate the social, financial and environmental effects of energy supply interruptions for heavy electricity users using the case study of the Richards Bay Smelter. Energy supply is very important in the modern lives that people and organisations find themselves existing in, where operations are industrialised and digitalised.

In terms of social impacts, energy supply interruptions can have a devastating effect on the lives and well-being of citizens, particularly those who rely on electricity for medical equipment, heating and cooling, and other essential needs. From a financial aspect, interruptions can lead to lost productivity, increased operation and

maintenance costs, and potential damage to equipment and machinery (An & Mikhaylov, 2020). It is therefore the purpose of the proposed study to look at the social, environmental and financial impact of energy supply interruption in Richards Bay smelter.

1.3 Context of the Study

The proposed study looks at the impact of energy supply interruptions in the context of South Africa, specifically looking at the social, environmental and financial impact in the Richards Bay smelter. According to statistics and research, industries such as smelters are heavy users of electricity in South Africa and consume a significant portion of the country's electricity supply, representing a major challenge for an already strained power grid (Erero, 2023).

According to a report by Statistics South Africa (2020), industrial users accounted for approximately 40% of the country's electricity consumption in 2019, while residential and commercial users contributed to the remaining 60%. The report also highlighted that electricity consumption in South Africa has been steadily increasing that is up to 2019, with the total electricity delivered to customers rising by 1.2% from 2018 to 2019 (Banderker, 2022). From 2019 to 2023, South Africa’s energy demand pattern has not been consistent due to factors such as the Covid-19 pandemic, which saw the period being synonymous with decline, partial recovery, and stagnation (Koch, Nkuna & Ye, 2024).

The disruptions in power supply have led to production downtime, reduced product quality, increased operating costs, and hindered long-term investment in the industry. In a global context, factors such as surging electricity costs, unreliable energy availability, and an overreliance on coal-powered energy sources have diminished South Africa’s competitiveness relative to nations like Qatar, Iceland, and Canada, which boast abundant, inexpensive, and renewable energy resources (Payton, 2023).

These countries also enjoy robust infrastructure, strategic proximity to major markets, and alignment with global sustainability initiatives, elements that are increasingly crucial for attracting investments in aluminium smelting. As the global market shifts towards a preference for low-carbon aluminium, the South African aluminium sector must navigate the challenge of adhering to these new standards while grappling with

persistent energy issues (Payton, 2023). This situation prompts important questions regarding the feasibility of future investments in the sector and whether alternative approaches should be explored to maintain competitiveness in the international arena

Addressing the root causes of load shedding is vital; however, the key question is whether investing in the smelting industry is the best use of South Africa's resources. The nation does not possess a comparative advantage in aluminium smelting due to high electricity costs and dependence on coal-based energy, which hinder its global competitiveness (Masike, 2019). Rather than channelling additional resources into this energy-intensive sector, it may be more prudent to focus on optimising existing facilities, such as the Hillside smelter. This could involve evaluating the most efficient management strategies for current operations while considering alternative investment opportunities that better align with South Africa's economic capabilities and the evolving energy landscape.

1.4 Research Problem

South Africa is a country that has been facing numerous energy supply interruptions for many years now. These interruptions have on and hurt the country's economy, its industries, and the daily lives of its citizens. The problem of energy supply interruptions in South Africa is multifaceted and requires urgent attention to find a sustainable solution (Muller, 2023). One of the main causes of energy supply interruptions in South Africa is the ageing infrastructure of the country's power plants and distribution networks (Styan, 2019). Many of the power plants in South Africa are old and in need of significant upgrades and maintenance. The lack of investment in modernising the energy infrastructure has led to frequent breakdowns and outages, which in turn disrupt the energy supply to businesses and households (Banda, 2020).

The demand for electricity in the country often exceeds the available supply, resulting in load shedding and rolling blackouts. This not only affects the industrial sector but also impacts the daily lives of citizens who are left without electricity for extended periods, affecting their ability to work, study, and live comfortably. Mismanagement and corruption have led to inefficiencies in the operation and maintenance of power plants, as well as delayed investments in new energy infrastructure (du Venage, 2020). This has further strained the already struggling energy supply in the country.

Statistics from the South African government indicate that the country has been experiencing frequent power outages and load shedding due to its struggling energy infrastructure. In 2019, South Africa experienced an unprecedented level of power cuts, with the state-owned power utility Eskom implementing load shedding regularly (du Venage, 2020). The impact of these power outages has been severe, affecting businesses, schools, hospitals, and households across the country. These power cuts have also had a significant negative effect on the economy, with estimates suggesting that they cost the country billions of dollars in lost productivity and revenue (du Venage, 2020).

The energy supply interruptions in South Africa have had a detrimental impact on the country's economy. Businesses have suffered from production losses, increased operating costs, and reduced competitiveness in the global market due to unreliable energy supply. The lack of access to consistent electricity has hindered the growth of small and medium enterprises, as well as discouraged foreign investment in the country. According to Nedbank (2023), 60% of township small businesses cannot have alternative energy sources in the case of an energy supply interruption, and 66% of township small businesses have shed jobs because of load-shedding

According to statistical data from the World Bank, power outages in South Africa cost the economy an estimated 100 billion rand (approximately $6.8 billion) per year. These costs result from lost productivity, disrupted business operations, and increased expenses for alternative energy sources. Additionally, the South African Chamber of Commerce and Industry reported that 77% of businesses in the country have experienced negative effects from power outages, including decreased production and increased operational costs.

The environmental impact of energy supply interruptions in South Africa is also evident from statistical data. The reliance on coal for electricity generation has led to significant carbon dioxide emissions, contributing to environmental degradation and climate change (Umar & Kunda-Wamuwi, 2019). In addition, the need for alternative energy sources during power outages, such as diesel generators, further contributes to air pollution and environmental degradation (Inglesi-Lotz, 2023).

The impact of load shedding on smelters is significant. Smelting operations are highly energy-intensive, and any interruption in the electricity supply can have severe

consequences. Load shedding disrupts the production process, as smelters rely on a continuous flow of electricity to maintain the high temperatures required for the smelting process. When the power supply is cut off, the entire operation has to be stopped, and the molten metal may solidify, causing damage to the equipment and leading to significant downtime (Walsh, Theron & Reeders, 2021).

1.5 Research Objectives

The proposed study is guided by the following objectives:

- To establish the social, environmental and financial impact of energy supply interruptions on the Richards Bay smelter.
- Investigate and assess the effects and impact of mitigation measures on the social, environmental, and financial implications of energy supply interruptions at the Richards Bay smelter.
- To propose mitigation measures to address the social, financial and environmental impacts of energy supply interruptions on the Richards Bay smelter.

1.6 Research Questions

To achieve the set objectives, the study will make use of the following research questions:

- What are the social, environmental and financial impacts of energy supply interruptions on the Richards Bay smelter?
- What are the effects and impact thereof of the mitigation measures undertaken to deal with the social, environmental and financial implications of energy supply interruptions on Richards Bay smelter?
- What mitigation measures can be proposed to address the social, financial and environmental impacts of energy supply interruptions on Richards Bay smelter?

1.7 Significance of the Study

Energy interruptions can have a significant impact on smelters and industrial and commercial facilities, in general, which rely heavily on a constant and reliable source of power to maintain their operations. These interruptions can lead to economic losses, production delays, and even negative effects on the environment and society (Styan, 2019). Therefore, understanding the mitigation measures being undertaken to deal with the social, environmental, and economic impact of energy interruptions on intensive electrical users such as smelters is of utmost importance (Miles, 2019).

Understanding the mitigation measures being undertaken to address the social and environmental impact of energy interruptions can also provide valuable information about the potential broader societal and environmental consequences of these interruptions. For example, the reliance on backup generators during energy interruptions can lead to increased air and noise pollution, which can have negative effects on public health and the environment (Mabunda, 2021). By understanding how industrial users are addressing these issues, the study can identify opportunities to promote more sustainable and environmentally friendly mitigation measures.

By gaining a better understanding of the challenges and obstacles faced by heavy electrical users in mitigating the impact of energy interruptions, policymakers and regulators can develop targeted interventions and support mechanisms to help these users build resilience and adapt to the changing energy landscape (Walsh, Theron & Reeders, 2021).

Understanding the mitigation measures being undertaken by industrial users can also have broader implications for the energy sector as a whole. By identifying best practices and successful strategies for mitigating the impacts of energy interruptions, this research can help inform the development of more resilient and reliable energy infrastructure and systems, benefiting not only the Richards Bay smelter but also the wider community and society.

1.8 Delimitations of Study

Delimitations are the boundaries that the researcher sets in a research study, deciding what to include and what to exclude, and they help to narrow down the study and make it more manageable and relevant to the research goal (Mishra & Alok, 2022). In the context of the proposed study, the study is limited to the parameters of the Richards

Bay smelter. The study is also limited to participants drawn from the senior management of the Hillside smelter.

1.9 Definitions of Terms

The following are the operational definitions that will be used on key terms that will be very much key and visible during the rest of the study:

1.9.1 Energy supply interruptions

This is going to be a term that will feature a lot in the subject. The term is defined as the loss of electric supply to one or more consumers (De Vos, 2019). The study defines energy supply interruptions as a national energy supply shortage that ensures that electricity is not available for a certain period.

1.9.2 Smelter

A smelter is an industrial facility used to extract metal from its ore through heating and melting processes (Holmberg & Sandbrook, 2019). In the context of this study, it refers to the Richards Bay smelter, a key industrial operation dependent on a consistent electricity supply for its metallurgical processes.

1.9.3 Social Impact

This refers to the effect of energy supply interruptions on people, communities, and their quality of life (Stinchcomb, 2023). It includes aspects such as employment, health, safety, and social stability within the communities that depend on the smelter and related industries.

1.9.4 Environmental Impact

The environmental impact encompasses the consequences of energy disruptions on natural ecosystems (Holmberg & Sandbrook, 2019). This includes increased emissions from backup generators, changes in waste management practices, or unintended environmental degradation resulting from operational disruptions or shutdowns.

1.9.5 Financial Impact

This term refers to the economic consequences experienced by the smelter and its stakeholders due to power supply interruptions (Stevenson et al., 2021). It includes direct losses (e.g., halted production, equipment damage) and indirect losses (e.g., contractual penalties, reduced investor confidence, increased operational costs).

1.10 Assumptions

An assumption is defined as an unexamined belief; what we think without realising we think it. The proposed study assumes that Richards Bay smelters suffer a lot due to energy interruptions, and their challenges as a result have a bearing on the social, financial and environmental aspects of the community they operate.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The thrust of this chapter is premised on the need to provide a critical analysis of the existing literature on the subject matter. Literature reviews provide an opportunity for the study to see and even evaluate successful and unsuccessful assessment and research methods in one's field of study. A proper literature review prevents the study from duplicating the same information but allows the study to find its niche area that has not been addressed by the existing literature on the subject matter.

2.2 Conceptualisation of Key Terms

It is imperative to define the key terms in this study to have operational definitions. The following are the key terms that are required to be conceptualised.

2.2.1 Social

The term 'social' refers to anything that is related to society or the interactions and relationships between individuals within a community, and it encompasses all aspects of human life that involve communication, collaboration, and cooperation with others (Stevenson et al., 2021). The meaning of the term social is deeply rooted in the concept of society and how people interact with one another, and it encompasses a wide range of activities, behaviours, and institutions that shape the way individuals live and interact with each other (Stinchcomb, 2023).

At its core, the term social is about human connections and relationships. It encompasses the way individuals interact with one another, form social bonds, and engage in activities that are in the interest of the community (Weber, 2023). One of the key elements of the term social is the concept of social organisation. This refers to the way individuals and groups organise themselves within a society. This can include

the formation of social institutions, such as government, education, and religion, as well as the development of social norms, values, and beliefs (Babbie, 2020).

The study understands the term ‘social’ as a term that entails the way individuals live, interact, and collaborate with others within a community. This study is of the view that the term represents the interconnectedness of human relationships and the importance of working together to create a better society for all. The study understands the term as an essential part of human life and plays a crucial role in shaping our identity, beliefs, and actions within the communities we belong to.

2.2.2 Environmental

The term ‘environmental’ refers to all aspects of the natural world and its interaction with human activities, and it encompasses the physical, chemical, and biological components of the Earth, as well as the social and economic systems that depend on them (Holmberg & Sandbrook, 2019). The concept of environmentalism emphasises the importance of preserving and protecting the environment for the well-being of present and future generations (Holmberg & Sandbrook, 2019).

It is imperative to state that the meaning of the term ‘environmental’ has evolved, reflecting changing attitudes towards nature and our relationship with it. In the past, the environment was often seen as a resource to be exploited for human benefit, without much consideration for the long-term consequences (Brady, 2019). However, as the impacts of industrialisation, urbanisation, and climate change have become more apparent, society has become increasingly aware of the need to conserve and sustainably manage the natural world (Ingold, 2021).

One of the key aspects of the term ‘environmental’ is the recognition of the interconnectedness of all living and non-living things. The environment is a complex system of interdependent components, where changes in one part can have cascading effects on the whole. This interconnectedness is important to consider when making decisions that affect the environment, as it highlights the need for a holistic and integrated approach to environmental management (Brady, 2019).

The study understands the term ‘environmental’ as a term that encompasses a broad and multidimensional concept that reflects our understanding of the natural world and

our role within it (Smith & Jacques, 2022). The study understands that the term emphasises the need for conservation, preservation, and sustainable management of the environment, and recognises the interconnectedness and intrinsic value of nature. It also highlights the social and ethical dimensions of our relationship with the environment and calls for a more holistic and integrated approach to environmental management (Smith & Jacques, 2022).

2.2.3 Financial

The term 'financial' refers to anything that relates to money or the management of money. It encompasses a wide range of activities, from budgeting and investing to banking and accounting (Brooks, 2019). It is a crucial aspect of both personal and business life, as it directly impacts one's ability to meet financial goals and obligations.

At its core, the term 'financial' entails the effective and responsible management of funds (Brooks, 2019). This includes making decisions about spending, saving, investing, and borrowing. It also involves understanding and managing financial risk, such as fluctuations in the stock market or changes in interest rates (Brooks, 2019).

The study understands the term ‘financial’ as one that provides a wide range of concepts and practices related to money and the management of money. It is a fundamental aspect of individual and organisational success, and understanding its principles and practices is essential for achieving financial security and prosperity.

2.2.4 Energy Supply Interruption

Energy supply interruption refers to a situation in which the regular supply of energy, such as electricity, gas, or oil, is disrupted for a significant period, and this can occur due to a variety of reasons, including natural disasters, equipment failures, or human intervention (Mišík, 2022). The consequences of an energy supply interruption can be severe, as it can lead to significant disruptions in daily life, economic loss, and, in some cases, pose a threat to public health and safety, as observed by Shao and Jin (2020).

The study understands energy supply interruption as the disruption of regular energy supply, with a specific focus on electricity. The study understands that energy supply interruption can have significant ramifications for individuals, businesses, and

communities. Whether caused by natural disasters, equipment failures, or human intervention, energy supply interruptions can lead to a range of challenges, including economic loss, public health and safety risks, and societal disruption.

2.3 Theoretical Framework

Theoretical frameworks influence how a study is designed and carried out, and also the interpretation of data. The study makes use of two theories that complement each other by setting up a strong theoretical foundational understanding. The two theories used by the study are the Economics of Power System Reliability and Planning theory, and the Contingency theory. The focus of the study is mainly on the electricity aspect of energy supply interruption, which is a major problem for both industrial and domestic energy consumers in South Africa. The Economics of Power System Reliability and Planning theory provides an explanation of how electricity, as an energy source, has to be distributed to consumers for optimum efficiency in an industrial setup. The contingency theory focuses on the measures that are undertaken by the industry to deal with the energy supply interruption.

2.3.1 The Contingency Theory

The study makes use of the contingency theory in its quest to explain the impact of energy supply interruptions on the social, environmental and financial aspects of the Richards Bay smelter. Contingency theory is an organisational theory that claims that there is no best way to organise a corporation, to lead a company, or to make decisions (Memane et al., 2019). Instead, the optimal course of action is contingent (dependent) upon the internal and external situation. Contingent leaders are flexible in choosing and adapting to succinct strategies to suit the change in situation at a particular period in time in the running of the organisation (Memane et al., 2019).

Contingency theory suggests that there is no one-size-fits-all approach to management and that the most effective way to manage a situation depends on various factors (Csaszar & Ostler, 2020). It is estimated that South Africa's power crisis will continue until 2025, and blackouts will take 5 years to phase out (Winkler, 2023). South Africa has been dogged since 2008 by rolling blackouts that have grown steadily worse despite repeated government pledges to end them (Walsh, Theron & Reeders,

2021). Electricity is sometimes unavailable for 10 hours a day. The shortfall is the consequence of frequent breakdowns at its ageing coal power plants, which constitute 74% of the country's generating capacity (Winkler, 2023).

Rejc (2004) summarised the main ideas underlying contingency, and they are as follows:

- Organisations are open systems that need careful management to satisfy and balance internal needs and adapt to environmental circumstances
- There is not one best way of organising. The appropriate form depends on the kind of task or environment one is dealing with.
- Management must be concerned, above all else, with achieving alignments and good fits
- Different types or specifics of organisations are needed in different types of environments.

Contingency theory from a structural aspect holds that the effect on organisational performance of organisational structure depends upon how far the structure fits the contingencies, such as uncertainty, strategy, and size (McAdam, Miller & McSorley, 2019). Organisations facing low uncertainty are fitted by specialised and centralised hierarchical structures, whereas organisations facing high uncertainty are fitted by lower specialisation and decentralisation (i.e., decisions being taken at lower levels of the hierarchy) (Mohammad & Bujang, 2019).

2.3.1.1 Applicability of the theory in the context of energy supply interruptions in South Africa

Contingency theory, therefore, expects that entities have to come up with solutions to deal with the problem, in this case, the problem of energy supply interruption at a Richards Bay smelter. A basic tenet of contingency management is that no single management strategy will work for every company. Three separate possibilities are identified by the theory: favourable, unfavourable, and intermediate. These are the three outcomes that could occur (Rouma, 2022). At the core of this theory is the

emphasis on the importance of adapting to change and being flexible to effectively navigate through a dynamic environment (Safari & Saleh, 2020).

Contingency theory provides a framework for understanding and addressing the challenges associated with energy supply interruptions. The theory emphasises the need for businesses to be adaptable and flexible in their operations to effectively deal with the disruptions caused by load shedding (Eriksson, Bigi & Bonera, 2020). One way in which businesses can apply contingency theory to address this issue is by developing contingency plans that outline alternative strategies and resources to be utilised in the event of an energy supply interruption (Eriksson, Bigi & Bonera, 2020). These plans should include measures such as backup power sources, scheduling of operations during non-peak hours, and reassigning tasks to maximise productivity during times of electricity shortages (Safari & Saleh, 2020).

Another important aspect of contingency theory that applies to South African businesses dealing with load shedding is the concept of environmental uncertainty. Energy supply interruptions create a high level of uncertainty for businesses as they are unable to predict when the power cuts will occur and for how long. This can have a significant impact on operations and productivity. Contingency theory suggests that businesses should be proactive in identifying and addressing environmental uncertainties through effective planning and the development of flexible strategies (Eriksson, Bigi & Bonera, 2020). In the case of load shedding, businesses can adopt measures such as investing in renewable energy sources, implementing energy-efficient technologies, and diversifying their supply chain to reduce their dependency on electricity.

Contingency theory emphasises the importance of effective leadership and decision-making in navigating uncertain and changing environments. Business leaders in South Africa must be able to make quick and informed decisions in response to energy supply interruptions to minimise their impact on their operations (Araral, 2020). This involves considering the specific context in which the business operates and making strategic decisions that are contingent upon the unique circumstances presented by load shedding (Rouma, 2022).

2.3.2 The Economics of Power System Reliability and Planning Theory

The theory of power system reliability focuses on the ability of a power system to deliver electricity to end-users with a certain level of dependability (Adefarati & Bansal, 2019). This theory involves the analysis of various components, such as generation, transmission, and distribution, to ensure that the system can withstand potential disruptions and maintain a continuous supply of electricity (Deng & Lv, 2020). Its principal objective is a description of the proper reliability analysis and planning techniques, using which electricity can be delivered from its generating source to the consumer most economically and with the least inconvenience (Dagoumas & Koltsaklis, 2019).

In the context of South Africa, the reliability of the power system has been a major concern, with frequent brownouts and blackouts impacting consumers, businesses, and the overall economy. The economic implications of power system reliability are substantial. The cost of power outages can be significant, resulting in lost productivity, damage to equipment, and inconvenience for consumers. In addition, unreliable electricity supply can deter potential investors and negatively impact economic growth (Ghiasi, Ghadimi & Ahmadinia, 2019). Therefore, applying the principles of power system reliability theory is crucial in mitigating the economic costs associated with electricity interruptions.

Planning theory in the context of the electricity sector involves the analysis of future electricity demand and the development of strategies to ensure that there is an adequate supply of electricity to meet this demand (Dagoumas & Koltsaklis, 2019). This includes the identification of potential investment opportunities in new generation capacity, transmission, and distribution infrastructure (Dagoumas & Koltsaklis, 2019). In South Africa, insufficient investment in new capacity and infrastructure has contributed to the current electricity challenges, with some regions experiencing supply constraints and interruptions.

The planning theory framework provides a systematic approach to identifying the optimal mix of generation technologies, considering factors such as cost, environmental impact, and reliability (Akpeji et al., 2020). Additionally, it offers a means of evaluating the trade-offs between different investment options and considering their long-term implications on the overall electricity system (Akpeji et al., 2020). By applying the principles of planning theory, policymakers and industry

stakeholders can develop a coordinated and strategic approach to addressing South Africa's electricity challenges.

The economic principles of power system reliability and planning theory have substantial applicability in understanding and addressing South Africa's electricity challenges. By applying these theories, policymakers and industry stakeholders can develop strategies to enhance the electricity system's reliability and plan for future demand to ensure a sustainable and efficient electricity supply. Addressing the country's electricity challenges is crucial for promoting economic growth, attracting investment, and improving the quality of life for all South Africans.

2.4 Global Energy Needs for Smelters

The energy demands of smelters represent a crucial aspect of industrial activities across the globe, particularly in the metals sector, including aluminium, zinc, and copper production. Smelting is a notably energy-intensive process, with electricity serving as the main energy source, especially for aluminium manufacturing. The global energy landscape for smelters is characterised by regional discrepancies in energy sources, supply reliability, and the economic ramifications of energy availability. Facilities engaged in aluminium smelting are among the most energy-demanding industrial operations worldwide.

According to the International Aluminium Institute (2023) the global aluminium sector accounts for approximately 3% of the total electricity generated worldwide. This significant energy consumption is largely attributed to the electrolytic reduction process inherent in aluminium smelting, which necessitates a steady and dependable electricity supply. It is estimated that producing a single ton of aluminium requires approximately 14,500 to 15,000 kilowatt-hours (kWh) of electricity (Pérez et al., 2021).

In regions such as Europe, the energy consumption of smelters has emerged as a critical concern, especially in light of recent surges in energy prices. European smelters, which have traditionally operated on a blend of coal, natural gas, and hydroelectric power, have faced significant challenges due to the ongoing energy crisis intensified by the conflict in Ukraine and the resulting sanctions on Russian energy exports (Rötzer & Schmidt, 2020). The soaring electricity costs have constrained production capacities, prompting some smelters to suspend operations entirely. A

notable example is Alcoa’s San Ciprian smelter in Spain, which announced a two-year suspension of its aluminium smelting activities due to prohibitive energy prices. This decision highlights the vulnerability of smelters to fluctuations in energy costs (Mudd, 2020).

The reliability of energy supply is essential for smelting operations, as power interruptions can result in significant operational and financial setbacks. In Africa, the smelting sector faces distinct challenges due to the continent's relatively undeveloped energy infrastructure (Tabereaux, 2023). For instance, South Africa, which hosts one of the Southern Hemisphere's largest aluminium smelters, has been plagued by frequent power outages (Nakanwagi, 2023).

These outages have stemmed from factors such as ageing infrastructure, insufficient investment in power generation, and the ongoing shift from coal to renewable energy sources. Consequently, these interruptions have not only disrupted production but have also escalated operational costs and diminished the region's international competitiveness (Nakanwagi, 2023).

Similarly, in Europe, the recent energy crisis has prompted numerous smelter closures. The European aluminium sector has seen a significant drop in output as energy costs surged, with some facilities slashing production by as much as 50% (Tabereaux, 2023). This decline in capacity has reverberated throughout the supply chain, driving up the costs of raw materials and finished products, and jeopardising the viability of downstream industries dependent on aluminium. The shrinking smelting capacity in Europe has raised alarm about the industry's long-term sustainability, especially amid ongoing energy price fluctuations and the increasing push for greener energy alternatives (Zhang, 2023).

The aluminium smelting industry in Europe has been significantly affected by the ongoing energy crisis. With European nations heavily reliant on Russian natural gas and the imposition of sanctions, many have had to urgently seek alternative energy sources, resulting in a surge in coal consumption in some areas (Nakanwagi, 2023). Despite attempts to secure stable energy supplies, the soaring electricity prices have rendered it economically unfeasible for numerous smelters to operate at their full potential. Consequently, this has triggered a wave of smelter closures and a decline

in production, potentially ushering in long-term structural shifts within the industry (Zhang, 2023).

Conversely, Africa faces a different yet equally daunting set of challenges. The continent's energy infrastructure remains underdeveloped, with many smelters dependent on a mix of hydroelectric power and coal. The transition toward renewable energy and the gradual reduction of coal usage have created additional hurdles. These power interruptions have not only disrupted production but have also escalated operational costs and diminished the sector's competitiveness in the global marketplace.

2.5 Energy Needs for a Richards Bay Smelter

The study must understand the energy needs for the Richards Bay smelter to be in a position to make a sound conclusion. The smelter in question for the study is the Hillside Aluminium smelter in Richards Bay, in the province of KwaZulu-Natal, owned by South32 (Zhang, 2023). The aluminium smelter in Richards Bay, South Africa, is a crucial part of the region's economy. It is also one of the largest industrial consumers of electricity in the country (Bird, von Gruenewaldt & Petzer, 2022). The energy needs of the aluminium smelter in Richards Bay are considerable, and understanding them is essential to grasp the broader context of the smelter's operation and its impact on the local and national energy infrastructure.

Aluminium smelting is a highly energy-intensive process. The primary energy requirement for aluminium smelting is electricity. The smelting process involves the refining of aluminium oxide, also known as alumina, into aluminium metal through electrolysis (Mioche, 2019). This process requires high temperatures of around 950 degrees Celsius and a significant amount of electricity to separate the aluminium from the oxygen (Mioche, 2019). The smelter has a capacity of 720,000 metric tons of primary aluminium per year, making it one of the largest smelters in the world. To maintain its operations at this scale, the smelter requires a substantial and consistent supply of electricity (Ndandani, 2020).

The energy needs of the aluminium smelter in Richards Bay are met by the local electricity grid, which is primarily supplied by the state-owned utility, Eskom. Eskom generates electricity from a mix of sources, including coal, renewable energy, and

nuclear power (McKay, 2021). However, the majority of the electricity used by the smelter comes from coal-fired power plants, which are the dominant source of electricity in South Africa.

The reliance on coal-fired power for the smelter's energy needs has several implications. Firstly, it means that the smelter's operations are dependent on the availability and affordability of coal-generated electricity. This dependence exposes the smelter to the volatility of coal prices and the potential for supply disruptions in the coal supply chain (Coetzee & Kleynhans, 2019). The use of coal-fired electricity for the smelter's energy needs raises environmental concerns. Coal combustion is a major source of greenhouse gas emissions and air pollutants, contributing to climate change and public health risks (Bond, 2023). As a result, the aluminium smelter's energy use is closely tied to the debate on energy transition and the need to decarbonise the South African economy.

In recent years, there has been a growing effort to diversify the energy sources for the smelter. South32 has explored the possibility of sourcing renewable energy for the smelter, such as solar and wind power. In 2019, BHP Billiton signed a memorandum of understanding with Eskom to investigate the development of a renewable energy plant to supply the smelter's energy needs (McKay, 2021). This potential shift towards renewables aligns with global trends in the aluminium industry, where companies are seeking to reduce their carbon footprint and increase the use of sustainable energy sources.

The Hillside smelter has also faced public criticism on an electricity supply deal the company agreed with Eskom. Hillside consumes about 5% of Eskom’s electricity, about 1 205MW a year (McKay, 2021). South32 had a contract priced in US dollars, which expired in 2020 and had been in effect since 1995. In 2021, the smelter signed a new 10 year-deal with Eskom, which allows the energy utility to effect energy rationing to the company, unlike the previous deal, which shielded the company from experiencing such (McKay, 2021).

Several stakeholders were of the view that the deal was not fair on the part that the price the smelter was charged was 17 cents per kilowatt hour (kWh) while the rest of the country’s other heavy industries were paying R3.15/kWh (McKay, 2021). It took the energy regulator to change some of the terms of the deal, which saw the company

paying significantly higher, but the benefit was energy security for 10 more years, which is a critical factor for the sustainability of operations.

2.6 Social Impact of Energy Supply Interruptions

The study must look at the existing literature and what it denotes about the social impact of energy supply interruptions. Several studies have shown that several social aspects are consequences of the impact of energy interruptions. The following are some of the social impacts of energy supply interruptions from an industrial contextual aspect:

2.6.1 Worker Safety and Health Risks

Banderker (2022) observed that energy supply interruptions can compromise workplace safety and expose workers to hazardous conditions. In industries where machinery and equipment require electricity to operate safely, sudden interruptions can increase the risk of accidents, injuries, and even fatalities (Wiese & van der Westhuizen, 2024). Moreover, prolonged interruptions may lead to discomfort due to inadequate heating, ventilation, or lighting, affecting workers' physical well-being and productivity. Khan and Begum (2020) observed that without power, essential safety systems such as emergency lighting, fire alarms, and ventilation systems also become inoperable, potentially putting employees at risk of injury or harm.

In the context of public service, Robbins, Hintz and Moore (2022) observed that public servants' safety is compromised as they are the recipients of insults and negative comments from the public who would have come to access services, but then are not able to do so due to energy interruptions. According to the Public Servants Association (PSA) (2023) as cited by Cameron (2024) employees are exposed to verbal and physical abuse by clients as they are unable to perform most duties during load-shedding. The PSA (2023) further observed that energy interruptions further create health and safety risks to employees owing to non-functioning equipment, including air-conditioning in buildings.

Nkosi and Govender (2022) observed that energy interruptions can also lead to unsafe working conditions for employees. In another real-life case study from India, a software

company experienced frequent power interruptions due to load-shedding. As a result, employees were forced to work in dimly lit offices with inadequate air circulation, which increased the risk of accidents and health issues.

Marchetti-Mercer (2023) observed that load-shedding can also have long-term implications for employee well-being. A case study from Pakistan highlighted how prolonged load-shedding led to increased stress and fatigue among employees due to the disruption of work schedules and the uncertainty surrounding power availability (Marchetti-Mercer, 2023). This can impact mental and physical health, productivity, and overall job satisfaction. Entities must therefore prioritise employee well-being by implementing measures to mitigate the effects of load-shedding, such as flexible work hours, temporary relocation of workspaces, or providing mental health support.

2.6.2 Community Engagement and Stakeholder Relations

Any business entity has to protect its brand and have its brand be associated with professionalism and efficiency. However, the challenge with energy interruptions is premised on the fact that in many cases energy supply interruptions often occur with little to no warning, making it difficult for businesses to communicate effectively with stakeholders about disruptions in services or operations (Fatoki, 2022). This lack of timely communication potentially leads to frustration, confusion, and a breakdown in trust between businesses and their stakeholders, including customers, suppliers, employees, and local communities as observed by Fatoki (2022).

Energy-intensive industries may face scrutiny and backlash from local communities and stakeholders in the event of energy supply interruptions. Poor management of energy resources or inadequate contingency plans can erode trust and damage relationships between industry players and the communities they operate as has been observed by Mlambo (2023). Khan and Begum (2020) recommended that maintaining open communication, transparency, and proactive engagement with stakeholders is crucial for mitigating social tensions and building resilience in the face of disruptions.

2.6.3 Security and Crime Threats

Studies and reports have shown that there is a correlation between energy supply interruptions and heightened security threats. Criminals are taking advantage of load-

shedding under the cover of darkness, especially when it comes to business and residential-related crimes as observed by Lambongang (2023). Concerning the Western Cape Community Safety Report of 2023, on average, 25.7% of the sample analysed occurred during load-shedding. Crimes included burglaries (residential and business), theft from motor vehicles and theft of motor vehicles. The overall findings indicated that about 30% of crime is committed during load-shedding (Western Cape Department of Community Safety, 2023).

Energy supply interruptions compromise the effectiveness of security systems such as surveillance cameras, alarm systems, and access control mechanisms, leaving businesses vulnerable to theft, vandalism, and unauthorised access (Lawson, 2021). The absence of lighting and security systems during load-shedding periods can create opportunities for criminals to target businesses. Modipa (2022) observed that in Pakistan, frequent load-shedding has been associated with a rise in theft and burglary incidents, particularly in commercial areas where businesses are unable to afford backup power solutions or security personnel. Energy supply interruptions can also disrupt the functioning of electronic security systems, such as access control systems and alarm systems (Mabunda, Mukonza & Mudzanani, 2023).

Modipa (2022) observed that energy interruptions have a detrimental impact on the security of business operations in the digital realm. Many businesses today rely heavily on technology and data to operate efficiently, and power outages can disrupt their ability to access crucial information and communication systems. This not only poses a risk to the business's reputation and stability but also raises concerns about potential data breaches and security vulnerabilities (Modipa, 2022).

2.7 Financial Impact of Energy Supply Interruptions

Energy supply interruptions have a significant financial impact on South African businesses. These interruptions not only disrupt businesses' operations but also lead to increased costs and lost revenue. The financial impact of the interruptions is seen through the lenses of several aspects discussed below:

2.7.1 Loss of Productivity and Revenue

One of the most significant financial impacts of energy supply interruptions is the loss of productivity and revenue for businesses. When energy supply interruptions occur, operations come to a halt, leading to downtime (Mbomvu, et al., 2021). This downtime directly translates into lost production hours and missed business opportunities. For manufacturing companies, this can mean unfinished products, delayed shipments, and ultimately lost sales. For service-based industries, such as call centres or IT firms, interruptions can disrupt customer service and lead to dissatisfied clients (Walsh, Theron & Reeders, 2021).

According to The Outlier (2023), South Africa has experienced an estimated 6,776 hours of load-shedding in 2023, with 326 days of load-shedding so far. As of 04 December 2023, there have only been 12 days without load-shedding in 2023. A glance at the 2023 performance trading reports, mining companies and their CEOs have been outspoken about the deteriorating operating environment which prevents them from investing in South Africa. Exxaro's coal production decreased by 11% in 2022 due to the poor rail performance from Transnet and the structural constraint of inadequate electricity supply (SA Mining, 2023).

Sasol attributed its declining output to South Africa's deteriorating infrastructure and the "structural constraint" of load-shedding (Sasol, 2023). Sibanye-Stillwater observed that the increasingly supportive environment in Europe was in stark contrast to the operating environment in South Africa, which has continued to regress. Sibanye was of the view that South Africa's operating environment for miners was regressing due to ongoing load-shedding, the deteriorating quality of public services, and increased organised crime (Meyer & Neethling, 2023).

Small businesses in South Africa are heavily impacted by power outages as they are forced to shut down operations during power outages, resulting in a loss of productivity and revenue (Walsh, Theron & Reeders, 2021). The energy regulator NERSA estimates that the cost to the South African economy was nearly R35 billion in the 12 years between 2007 and 2019. Had all the load shedding experienced over the period taken place in a single quarter in 2019, it would have resulted in a 5% contraction in real GDP growth (Naidoo, 2023). Fraser (2023) reported that overall, the estimated economic impact of load shedding in 2022 was said to be around R560 billion.

A survey by Sakeliga (2021) showed that the median business reported a loss of around R25,000 over the preceding three months due to electricity shortages (or about R8,000 per month). Only around 10% of respondents in the survey reported no perceptible losses, while under 1% (0,6%) appear to derive more revenue from energy supply outages, perhaps by supplying goods and services that help households and businesses deal with Eskom shortages, like solar energy enterprises (Sakeliga, 2021).

Umar and Kunda-Wamuwi (2019) observed that when companies are unable to operate at their full capacity due to power outages, they are unable to meet production targets and fulfil orders on time. This tends to lead to missed opportunities and lost sales, as customers may turn to competitors who can deliver products and services more reliably, and additionally, businesses may have to compensate for delays in delivery or production, leading to further financial losses (Umar & Kunda-Wamuwi, 2019).

2.7.2 Increased Production Cost

It is human nature to solve a problem; however, solving a problem comes with a cost, and this also applies to both domestic and commercial energy users. South Africa, as has been mentioned earlier, has a challenge with its electricity security, which is not sufficient. Households and businesses are now being forced to invest in other forms of backup energy to deal with energy interruptions (Mabunda, Mukonza & Mudzanani, 2023).

The median business reported spending close to R5,000 per month on electricity, plus an additional R5,000 to curb the impact of Eskom power cuts. This includes spending on generators, UPS systems, solar systems, or other solutions (Inglesi-Lotz, 2023). Looking at the retail sector, Fraser (2023) reported that South Africa's biggest retailers have spent over R2.4 billion to mitigate the effects of energy outages. Alternatives to deal with energy supply interruptions in the retail sector are now accounting for more than the rental cost (Fraser, 2023).

According to data published by the South African Reserve Bank, Stage 6 load shedding costs between R204 million to R900 million per day, and the total accumulated cost of load shedding has exceeded R1.2 trillion so far. Specifically looking at the mining sector, mining operations require significant amounts of energy

to power equipment, ventilation, processing and other systems (Baker & Burton, 2024). The energy bill in the mining sector accounts for 10–40% of operating costs for mines (Fraser, 2023). With volatile fossil fuel prices and climbing electricity rates, energy costs have become a major pain point for industry.

Butler (2023) reported that Vodacom has spent over $200m on backup power in South Africa since 2020. Mzekandaba (2023) reported that Sentech witnessed a steep rise in diesel costs between 2022 and 2023, spending more than R2 million per month to keep some sites operational during rolling blackouts. Nedbank (2023) reported that South Africans spent around R1.2 billion on private power generation to escape Eskom and load shedding in 2022, with the bank expecting an even bigger spend in 2023. Back-up systems such as solar systems are notoriously expensive, and generators are associated with ever-increasing diesel prices (Fraser, 2023).

Businesses also have production costs based on paying their employees overtime to finish tasks that would have been affected by energy supply interruptions. Employees have to work overtime to meet the targets they would have been in a position to complete in their normal working hours, but because of power outages, especially during periods when the outages are on hire stages (Mzekandaba, 2023).

2.7.3 Supply Chain Disruptions

Energy supply interruptions have a direct impact on production and operational efficiency. Energy supply interruptions have the propensity to disrupt the entire supply chain, affecting not only a business's operations but also its suppliers and customers (Walsh, Theron & Reeders, 2021). Delays in receiving raw materials or components can lead to production bottlenecks and inventory shortages, further exacerbating financial losses. Similarly, businesses may struggle to fulfil orders or meet delivery deadlines, damaging their relationships with clients and partners (Walsh, Theron & Reeders, 2021).

Many businesses rely on a consistent and reliable energy supply to power their operations, whether it's for manufacturing processes, transportation, or storage facilities and when these energy supply interruptions occur, production delays, increased downtime, and decreased productivity are the results (Ateba, Prinsloo & Gawlik, 2019). The result of these upsets in the supply chain, in turn, tends to disrupt

the entire supply chain, leading to delays in fulfilling orders, missed delivery deadlines, and ultimately, dissatisfied customers.

For supply chain management to be successful, it needs consistency. But thanks to load-shedding, factors like delivery schedules could become disrupted (Nkosi & Govender, 2022). This would then cause delays, which could paralyse the entire supply chain. The impact of energy supply interruptions on South African businesses' supply chains is not limited to production and operational challenges. It also has a broader impact on the overall economy and its competitiveness in the global marketplace. South African businesses are at a disadvantage compared to their international counterparts, as they struggle to maintain consistent and reliable supply chains due to energy supply interruptions (Magagula, Meyer & Niemann, 2020).

Statistics South Africa (2023) found that mining output decreased by 2.6% in March 2023 as compared with 2022, and the consistent decline in overall infrastructure stability across both the electrical grid and other factors, such as Transnet, has seen the sector lose R150 billion in export value over the past year. In March 2023, Fitch published a review of the impact of energy outages across multiple sectors and revised its assessment of mineral production growth forecasts from 0% to -1% year-on-year for iron ore, and from 2% to -2% for platinum.

The mining and the mining-associated industries (smelting) dominate the headlines as it is a leading consumer of power, a leading taxpayer, and a significant provider of employment, contributing a major percentage to the country’s GDP and South Africa’s position as the fifth-largest mining economy in the world (Jonathan, Mafini & Bhadury, 2020).

2.8 Environmental Impact of Energy Interruptions

Energy supply interruptions can have a detrimental impact on the environment, as well as the productivity and profitability of these industries. The environmental impact of energy supply interruptions on the South African manufacturing and mining industry is multi-faceted. When the energy supply is disrupted, these industries often resort to using diesel generators as an alternative source of power (Ateba, Prinsloo & Gawlik, 2019).

While these generators provide a temporary solution, they emit harmful pollutants into the atmosphere, contributing to air pollution and the degradation of air quality (Nkosi & Govender, 2022). This not only poses risks to the health and well-being of the surrounding communities, but it also leads to the accumulation of greenhouse gases, exacerbating climate change and its associated environmental impacts (Nkosi & Govender, 2022). These generators emit pollutants such as carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2), and particulate matter (PM) into the atmosphere. The increased use of diesel generators during load-shedding exacerbates air pollution levels, contributing to smog formation and worsening air quality in surrounding areas. This not only harms human health but also damages ecosystems and contributes to climate change (Tembe, 2023).

The reliance on diesel generators during energy supply interruptions also results in increased fuel consumption, leading to higher carbon emissions and further exacerbating environmental degradation (Erero, 2023). The extraction, transportation, and burning of fossil fuels contribute to the depletion of natural resources, habitat destruction, and the release of toxic chemicals and pollutants into the environment. The negative impact on the environment from increased carbon emissions and air pollution can have lasting effects on ecosystems, wildlife, and human health (Erero, 2023).

Certain manufacturing and mining processes require significant amounts of water for cooling, processing, and other operations. Energy supply interruptions can disrupt water supply systems, affecting industrial activities that rely on water-intensive processes (Majola & Langerman, 2023). Additionally, the increased use of backup generators may lead to higher water consumption for cooling purposes. Discharges from industrial processes, including mining operations, can also pollute water sources, further exacerbating environmental degradation (Mlambo, 2023).

Zulu and Maama (2023) observed that energy supply interruptions lead to disruptions in the manufacturing and mining processes, resulting in production delays and decreased efficiency. This not only affects the overall productivity and profitability of these industries but also leads to the wastage of resources and materials. Inefficiencies in production processes tend to lead to increased resource extraction,

energy consumption, and waste generation, further straining the environment and contributing to environmental degradation (Zulu & Maama, 2023).

Cloete, Pienaar and Van der Merwe (2023) observed that manufacturing and mining industries generate large quantities of waste, including hazardous materials such as tailings, slag, and chemical by-products. Energy supply interruptions can disrupt waste management systems, leading to the accumulation of waste on-site or inadequate treatment and disposal practices (Cloete, Pienaar & Van der Merwe, 2023). Improper waste management consequently results in soil contamination, groundwater pollution, and ecosystem degradation, posing risks to human health and the environment (Cloete, Pienaar & Van der Merwe, 2023).

Kgarose, Makhubela and Setaise (2023) raised an important observation by stating that prolonged energy supply interruptions tend to hinder the implementation of sustainable practices and technologies mainly in the energy-intensive manufacturing and mining industry sectors, on the basis that businesses tend to prioritise immediate resource allocation and emergency response over long-term environmental considerations. The scholars observed that such practices impede the progress towards adopting cleaner energy sources, reducing greenhouse gas emissions, and minimising environmental impact (Kgarose, Makhubela & Setaise, 2023).

It is important to note that addressing the environmental impacts of energy supply interruptions requires a multifaceted approach, including investments in renewable energy infrastructure, energy efficiency measures, and sustainable industrial practices (Mlambo, 2023). Additionally, regulatory frameworks and enforcement mechanisms play a crucial role in ensuring that industries adhere to environmental standards and minimise their ecological footprint. By addressing both the causes and consequences of energy supply interruptions, South Africa can work towards a more sustainable and resilient industrial sector that balances economic growth with environmental protection.

2.9 Literature Gap

The researcher has come to a realisation that the majority of the studies have been looking at each of the three critical aspects (financial, social and environmental) individually on different aspects. According to the knowledge of the researcher based

on the review of the literature, there is no study conducted investigating the energy supply interruptions on smelters in Richards Bay. One study which this study was exposed to, focused on energy use in smelters was focused on a Polokwane-based smelter and it was conducted over 10 years ago making it less relevant to understanding current trends.

This study seeks to provide critical knowledge on the impact energy supply interruptions are having on an entity that consumes 5% of the total energy output produced by Eskom. Such an entity that is energy intensive deservedly requires academic focus to understand the impact of energy supply interruptions if they are affecting Hillside Aluminium smelter in Richards Bay.

2.10 Chapter Summary

The chapter provided a critical discussion which started by conceptualisation of key terms and provided operational definitions that are adopted by the study. The chapter provided a discussion on the ways in which energy supply interruptions have an impact upon the South African economic sectors from a financial, social and environmental aspect. The chapter also identified the literature gap that the study will seek to fill up and address. The next chapter provides a research methodological discussion, explain the technical side of how the study was carried out.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter of the research study provides a more detailed explanation of the methodology used by the researcher to achieve the expected and desired objectives and aims of the research study. In this chapter, the focus will be on the explanation, which includes the adopted research method, research design, sample size, data collection approach and analysis and underpinning concerns of ethical considerations. This chapter provides explanations and the rationale behind the adoption of techniques or tools used in the study.

3.2 Research Method

Research methodology, according to Mettler and Raptis (2012), is a methodical process that a researcher adheres to when gathering data to produce a useful and well-informed judgment or conclusion. To accomplish the goals of this study, a mixed methods research methodology was used. The study aims to offer both quantitative and qualitative explanations that motivated the study's choice of mixed research strategy, to provide both quantitative and qualitative data on the financial, social and environmental impact of energy interruptions.

Using quantitative and qualitative approaches in a research study is known as mixed research methodology, or triangulation (Leedy & Ormrod, 1980). The advantage of

mixed methods research is that the study becomes more substantial and methodical because the strengths and shortcomings of each methodology complement each other when utilised together (Ivankova & Plano Clark, 2018).

A mixed research methodology, which is often referred to as triangulation, uses both quantitative and qualitative methodologies in a research study (Leedy & Ormrod, 1980). The benefit of using mixed methods research is that the weaknesses and strengths in each approach complement the other when used together and the study becomes more significant and systematic (Ivankova & Plano Clark, 2018).

Quantitative research focuses on numerical and statistical data aspects in examining the relationships between the variables (Snyder, 2019). Maree (2007) defines quantitative research as a process that is systematic and objective in the way numerical data is collected from a selected subgroup to "generalise the findings to the universe that is being studied". The reason behind the identification of quantitative methodologies in this investigative study from sampling to data analysis is to use its tenets of classifying and quantifying features, thus counting them and constructing an objective statistical explanation of what is observed.

Qualitative research methodology focuses on the subjective interrogation of attitudes, opinions and behaviour patterns to generate more narratives, rather than numbers (Park, 2016). Nieuwenhuis (2015) defines qualitative research methodology as a research methodology that relies on the linguistic aspect, which focuses on meaning, rather than statistical analyses. The main purpose of qualitative methodologies is to facilitate a subjective examination of attitudes, opinions and behaviour of sampled participants to generate narrative explanations of individual views of participants on the financial, environmental and social impacts of energy supply interruptions on the Richards Bay-based smelter.

3.3 Research Design

Research design is defined by Clark and Ivankova (2015), as the approach a study takes and the plan of action used to implement that approach. What, how, and why are the three main components of a research design (Babbie & Mouton, 2001). The intended techniques and processes for data collection, measurement, and analysis

are spelt out in a research design (Schindler & Cooper, 2014). According to Du Toit and Mouton (2013), research design is a comprehensive plan or guide that a researcher must adhere to when starting a study. It was decided to use the explanatory sequential mixed methods design, which is a simple research method design as defined by Creswell and Plano Clark (2023).

3.3.1 Explanatory Sequential Mixed Methods Design

According to Ivankova (2014), the explanatory sequential mixed methods design is a type of research where the primary goal is to employ qualitative findings to explain quantitative outcomes. Explanatory sequential mixed methods design is based on the idea that quantitative data only paints a basic picture of the phenomena; qualitative data fills in the details and adds more context (Stringer & Aragón, 2020).

According to Stringer and Aragón (2020), "explanatory" refers to qualitative data that helps to explain quantitative outcomes. Using this design technique has the benefit of giving the researcher an easy-to-implement master plan, which is essential for the research's conclusive position and the validity and dependability of the findings.

3.3.2 Research Philosophy

The research theory that directed this study must be explained. The study design was constructed using two philosophical philosophies, objectivism and post-positivism. First of all, the objectivism of this study is based on the ontological proposition that there is quantifiable reality regarding the financial, social and environmental impacts of energy supply interruptions on a Richards Bay-based smelter.

Due to the investigative nature of the research and the necessity for opinions and perceptions that objectivism ignores, post-positivism’s qualitative philosophical approach was included. The primary purpose of incorporating post-positivism philosophy into the research design was to support the subjectivism component, which is crucial when conducting an investigative study. Post-positivists hold that subjectivism exists in the world rather than it being a fixed entity.

According to subjectivism, rules and theoretical models may only be used to explain the cause-and-effect relationship of a specific phenomenon (Ivankova, 2014); findings from one sample cannot be applied to another. Common knowledge is not common. The foundation of this study's inquiry was the need to understand the impact thereof of energy supply interruptions on the operations of a smelter. As such, it is crucial to avoid extrapolating from personal experience.

3.3.3 Research Design

The primary goal of conducting a study should be understood by a researcher before beginning to design a research study. This will help to determine the most suitable research design to use (Ivankova, 2014). The three generally acknowledged goals of the research are explanatory, descriptive, and exploratory; these are the things that a researcher should be aware of and mindful of (Lochmiller & Lester, 2015). According to Leedy and Ormrod (2015), using all three design techniques gives a researcher a superior foundation on which to conduct an appropriate and knowledgeable research study.

As a result, to ensure that every facet was addressed, the researcher had to take into account the opinions of Leedy and Ormrod (2015) as well as the mixed character of the study approach that was selected early on. While the explanatory approach was used to concentrate on explaining issues and aspects involved, the descriptive approach was used to describe and explain situations and events to meet the qualitative needs of this study. The exploratory design approach is effective when the researcher has a new area of interest.

3.3.4 Data Collection Instruments

The study used questionnaires to capture both statistical and qualitative data. Clark (2019) states that questionnaires can be used in a mixed study and are the only data collection instrument. A mixed questionnaire includes both open-ended (exploratory) questions and standardised closed-ended items; the open-ended part provides qualitative data, and the closed-ended part provides quantitative data. The quantitative aspect of the questionnaire is seen by looking at the trends of the responses on an item. For instance, if 70% of the participants share the same view, that trend has to be

further interrogated by the questions that seek more explanations through short narrative responses. In a qualitative study, the focus will just be on the narratives however the quantitative aspect looks at the statistical trends that can be observed from the responses of the participants.

The statistical that the study refers to entails one that has to do with the responses of the 50 participants. The questionnaire is divided into two parts, the first focuses on getting simple responses such as yes or no. These responses provide an opportunity to get a statistical aspect and understand the numbers behind participants' responses to a question. The second part of the question seeks to get short narrative responses that provide brief explanations and are used as qualitative data.

3.4 Study Context

The study was carried out at the Hillside aluminium smelter based in Richards Bay which is also the workplace of the researcher. The Hillside aluminium smelter, located in Richards Bay, South Africa, is one of the largest aluminium smelters in the world, producing an estimated 700,000 tons of aluminium annually. The smelter is a major contributor to the local economy, employing a large number of individuals and providing significant revenue for the surrounding area. The smelter relies heavily on a consistent and reliable energy supply to operate efficiently, and any interruptions in energy supply can have critical social, financial, and environmental impacts on the facility and the local community (Mehlhorn, Newman & Haberzettl, 2024).

Richards Bay is a coastal town in the KwaZulu-Natal province of South Africa, known for its natural beauty and vibrant economy. The area is home to a diverse population and is also a hub for industrial activity, with the Richards Bay Industrial Development Zone (RBIDZ) hosting numerous industrial facilities, including the Hillside smelter. The smelter is a significant employer in the region, providing valuable job opportunities and steady income for many individuals and families in the area (Mehlhorn, Newman & Haberzettl, 2024).

3.5 Population and Sampling

This section describes the research population and sampling techniques used during the process of data collection. Generally, a population refers to an entire group or elements with common characteristics (Fetters, Curry & Creswell, 2013). Sampling is the process whereby a small proportion or subgroup of a population is selected for analysis (Rossman & Rallis, 2012).

3.5.1 Population size

Population refers to any group of people or subjects of study that a researcher intends to research on (Ivankova, 2014). In the context of this study, the population refers to employees of the Hillside aluminium smelter. Hillside aluminium smelter directly and indirectly supports more than 31,000 jobs (Creamer, 2023). The research sought to engage participants at the senior management level. Within this entity, senior management comprises mostly specialist engineers and departmental managers. It is imperative to note that the study is not targeting all the 31,000 employees but rather is only focusing on the senior management level which has an estimated population of 100 people. Therefore, the population size of the study stands at 100 people.

3.5.2 Sampling

Derived from the word "sample," sampling generally refers to the process of choosing units or objects from a population or group to get data for research (Stringer & Aragón, 2020). A sample is the portion of the complete population that a researcher examines and whose features will be applied to the entire population. Because the populations being investigated in the majority of human sciences research projects are too big, samples must be used (Stringer & Aragón, 2020). Sampling was critical to be done in the context of this study because it was not possible to reach out to more than 100 senior-level employees.

3.5.3 Sampling Technique

The study adopted a stratified sampling technique to come up with the participants who would take part in the study. In a stratified sample, researchers divide a population into homogeneous subpopulations called strata (the plural of stratum) based on

specific characteristics (e.g., race, gender identity, location, etc.). Every member of the population studied should be in exactly one stratum (Bhardwaj, 2019).

In the context of this study, the study divided the participants into two groups, that is one for operational management and the other for technical management. Concerning allocating the sample size of each stratum or category both proportional allocation and equal allocation were used. Proportional allocation is explained by Song and Kawai (2023) as how each stratum is allocated a number proportional to its population. Concerning the department selected, an equal allocation approach, in which each stratum is allocated the same number of elements, was adopted.

3.5.4 Sample Size

Although it's more costly, a large sample is more representative. As a result, choosing a suitable sample size is crucial. Although more feasible, a small sample has substantially lower accuracy (Lester, 2011). The following formula, which is equivalent to an online sample size calculator, was used to calculate the sample size for this study:

$$S = (z2\ (d(1 - d))/ e2) / 1 + (z2\ (d(1 - d)) / e2) \text{ where;}$$

S = sample size, P = population size, z = z-score, e = margin of error and d = standard deviation.

Using the target population of 100 senior management level employees, a confidence level of 95% and a margin of error of 5%, a sample size of 50 employees was reached in the study. This sample was manageable and representative enough of the whole target population in the sense that it accounted for 50% of the total population of the senior management. The size enables the study to reflect and generalise the study findings and conclusions to the entire population of the senior management level.

The basis of focusing only on senior management is premised on the understanding that senior management has a comprehensive understanding of the strategic and operational aspects of the organisation (Dawes &Topp, 2022). They can provide insights into how energy supply interruptions affect the company's long-term plans, strategic objectives, and overall performance. Senior managers have a broader view

of the company's operations, including cross-departmental impacts (Dawes & Topp, 2022).

3.5.5 Inclusion Criterion

Designations of participants were used to define the inclusion criteria. All participants who were involved in the study were within the parameters of being employees of Hillside Aluminium smelter based in Richards Bay and holding a position that is deemed as a senior management level position. Having a marked inclusion criterion is critical for the reliability of the study. It is important because the study has a primary target population that has experience and first-hand experience within the smelting industry to provide insight and knowledge.

3.5.6 Exclusion Criterion

Any worker who is not an employee or not in a senior management level position at the Hillside Aluminium smelter based in Richards Bay was for the above mentioned reasons excluded from the study.

3.5.7 Recruitment of Participants

The process of recruiting participants was conducted based on the willingness of employees. The researcher moved from office to office of prospective participants to fill out questionnaires with potential participants who showed interest and willingness to serve as research subjects. As explained in the previous section, an unbiased sampling technique is key throughout the research process.

3.6 Data Collection & Treatment

In general, the process of obtaining information from a sample of participants within a target population or group is referred to as data collection (Metler & Charles, 2011). The researcher had previously labelled and specified the specifications of the sample that would be used in this investigation. This section describes the methods, tools, and procedures for handling and analysing data.

3.6.1 Data Collection Tools

The research design had an impact on the data collection instruments, which were created and implemented to take into account the structure of the study. According to De Vos et al., (2011), data collecting should be carried out in a way that is consistent with the technique chosen for the study. The instruments used to collect the data were compliant with the study's mixed research approach. A questionnaire was utilised to gather both quantitative data and qualitative data. The following two subsections offer a thorough discussion of data collection tools

3.6.2 Questionnaires

A questionnaire, according to Robson (2002), is a set of questions assembled on a form for a responder to fill out regarding a research study. It is a research tool made up of several questions meant to gather information from participants. A questionnaire is also a set of questions that are given to participants via a variety of channels, such as personal (phone, intercept) or non-personal (mail, computer), and that they are required to answer (Babbie & Mouton, 2008). In order to facilitate the deduction and collection of statistics from respondents for statistical analysis, questionnaires are developed in such a way (Flick, 2011).

Questionnaires are less expensive than other data-gathering tools, require less labour than verbal or telephone surveys, and have standardised replies that make data analysis easier (Flick, 2011). Conversely, customers may become irritated by such identical reactions. The use of questionnaires is restricted by the need for respondents be able to read the questions and respond.

Likert-scale questionnaires were employed in this study to enable respondents to provide both subjective and objective answers. A Likert item is only a statement that is asked to be evaluated by the respondent based on any form of objective or subjective standard; usually, agreement or disagreement is gauged. Because there are an equal number of positive and negative locations, it is regarded as symmetric or "balanced" (Flick, 2011). A standard five-level Likert item looks like this: Agree, Disagree, Strongly Disagree, Neither Agree nor Disagree, and Agree. There were four sections in the questionnaire, each with a specific focus area (see Appendix A).

Potential responders were immediately accessible and nearby; therefore, it was handed by hand to them. It was distributed to various responders by randomly knocking on their workspaces and asking for their patience and time. According to Leedy and Ormrod (2015), the largest administrative drawback of using a self-administered questionnaire is that the researcher has no control over who fills it out or whether they seek advice from others. This is because the questionnaire is no longer in the researcher's hands or visible.

The fifth section of the questionnaire sought to get short descriptive explanations from the participants based on their responses to the section, which would require simple, straightforward responses. These descriptive responses provide the study with descriptive narratives that explain the skeleton provided by the four sections earlier.

3.7 Data Analysis

Data analysis, according to Ivankova and Wingo (2018), is a methodical procedure that reduces primary data acquired to manageable levels so that the researcher can recognise and discover patterns and trends, and provide an accurate and dependable summary of the data. This is important because it allows a researcher to properly understand the data findings and respond to the research question.

3.7.1 Interval Variables

Interval variables, sometimes referred to as measurable variables, were used in the current investigation. The rationale behind the research's use of interval variables is its status as the most advanced type of measurement, as well as the most straightforward and easiest to analyse and alter. Interval variables offer a platform for answering questions about, among other things, staff size, income, and revenue, all of which are crucial to the research (Rajasekar & Verma, 2013). Each variable in an interval has a definite and consistent space between them.

3.7.2 Data Matrix

The data matrix, which is the method by which the gathered data is examined and coded, is the subject of the following data analysis section once the data variable used

in the study has been determined. The Microsoft Excel Spreadsheet program was utilised because of its intuitive characteristics, which are essential for simplifying the study process. An Excel spreadsheet may be seen and distributed by email as an attachment, has no expense associated with it, and its files can be password-protected. Notwithstanding the software's advantages, some drawbacks are that macros can make the program vulnerable to viruses and that larger files may cause it to operate more slowly (Robson, 2020).

The numerical data analysis was done using Microsoft Excel in conjunction with Jeffreys's Amazing Statistics Program (JASP). JASP was chosen on the basis that it is appropriate for smaller data levels, such as from this study, and it was also used to test the hypothesis using the chi-square test for validity and reliability in light of the data.

3.7.3 Data Presentation

Research should use a suitable presentation strategy that considers the variable when presenting data. Bivariate analysis is the process of connecting and linking the relationship between variables once a researcher has determined how independent variables are behaving (Robson, 2002).

a. Qualitative data

With the help of grounded theory, the qualitative data, which came from the questionnaire responses from participants and took the form of brief, documented narratives, were conceptualised, coded, and categorised into themes and sub-themes. All observations were compiled into conceptual categories known as themes in a grounded theory manner.

b. Quantitative data

JASP was employed to conduct a thorough statistical descriptive analysis of the quantitative data, which included additional calculations and data-cleaning procedures. The initial step involved preprocessing the data, where the raw information collected from questionnaires was meticulously reviewed to identify and rectify any missing, inconsistent, or outlier values. This cleaning process was essential to ensure the dataset's accuracy and reliability. Following this, descriptive statistics

including means, medians, standard deviations, and frequency distributions were calculated to summarise the fundamental characteristics of the data. This provided a comprehensive overview of the social, environmental, and financial impacts under investigation.

The subsequent phase included a series of inferential statistical tests to examine the relationships and correlations among the key variables. For instance, Pearson correlation coefficients were computed to evaluate the strength and direction of the associations between energy supply disruptions and their effects on social, environmental, and financial domains. Regression analysis was conducted to ascertain the degree to which energy supply interruptions could predict variations in these impact areas. This approach facilitated the identification of significant predictors and the development of potential mitigation strategies. Through these statistical analyses, the study not only quantified the interrelationships among the variables but also offered insights into possible causal connections, insights that are vital for comprehending the broader implications of energy supply disruptions at the Richards Bay smelter.

3.7.4 Reliability and Assessment of Rigour Design

When evaluating complex themes, such in this instance as the impact of energy supply interruptions, mixed methods might be an efficient and likely research strategy. The study made use of a convergent design to compare research findings from qualitative and quantitative data components to validate the study. Convergent design is a technique used to show the rigour and quality of the research design. This leads to the simultaneous collection of the two types of data and the evaluation of the data findings using parallel constructs of the two types of data (Robson, 2020).

3.8 Ethical Considerations

The participants in this study were given a confidentiality statement, and their right to privacy and anonymity was respected. The data was gathered with the highest honesty and integrity, particularly when it came to how the questionnaire was administered. Aiming for a high response rate, the study also made sure there was no bias or attempt at persuasion (Bless & Higson-Smith, 2000). Participants received

assurances that the study would only be utilised for academic reasons and that taking part in it was completely voluntary.

3.8.1 Permission and Informed Consent

The study was conducted to eliminate any potential dangers of bias, self-serving motivations, and oversimplification of specific concerns that came up during the investigation. As a departmental extension of the university, the researcher entered the field. The participants were randomly selected were asked for permission to participate. Had they refused, randomly selected substitutes would have been identified in that specific stratum.

3.8.2 Confidentiality and Anonymity

Pseudonyms were used in place of participants' real names to protect their privacy. Everybody who took part was anonymous. The fact that the study's data collection and conclusions would only be used for academic reasons was also disclosed to the participants. No identifying information or personal information was disclosed, and the data remained extremely secure.

3.9 Chapter Summary

This chapter covered every step involved in carrying out the investigation and considered a rational flow that connects information to the stated research questions. The study methodology was examined, offering a more thorough justification for the selection of a mixed research approach. The process of gathering and analysing data was also covered, along with the demographic and sample elements. The ethical concerns that could impact this research project were also taken into account and talked about. The presentation of the study project's findings, analyses, and interpretation will be the main topics of the upcoming chapter.

CHAPTER 4

FINDINGS AND DISCUSSION

4.1 Introduction

The thrust of this chapter is premised on the need to provide a discussion on the research findings gathered from the participants who filled out the data on the questionnaires. The study recruited 50 participants, and they provided critical information that forms the basis of the data presented in this chapter. The study used descriptive statistics and thematic analysis on the basis that the study adopted a mixed research methodology. The questionnaire used by the study provided a part for participants to respond to both Likert-style and short narrative responses.

4.2 Demographic Profile

This part delves into the demographic details of those who were involved in the study. Section A of the questionnaire was designed to extract personal information that could shed light on the demographic characteristics of the people being studied. Talking about the demographic details of participants is crucial to this line of research. Demographics represent the kind of independent variables that are not subject to manipulation since they consist of the factual information that participants in a study provide (Gagnon, Johannsen & Lopez-Salido, 2021).

The study had 50 participants who were all employees of Hillside Aluminium Smelter based in Richards Bay. Imperative to this study were the demographic aspects of gender, age, employment position and level of education demographic profile aspects. These independent variables need to be scrutinised if they have a meaning and a relationship within the context of the views of the participants regarding the social, environmental and financial impact of energy supply interruption in Richards Bay smelter.

4.2.1 Age

In this study, the age of participants is a key demographic factor as it affects how they view the social, environmental, and financial impacts of energy supply interruptions. Older workers, due to their extensive experience, are by nature in possession of greater institutional knowledge as a result of working at the company for a longer time. Thus, they are in a position to provide better insights into the long-term operational disruptions caused by energy supply interruptions.

Meanwhile, on the other hand, younger employees are in a position to offer fresh perspectives on energy supply interruption. In terms of environmental awareness, older generations might be somewhat less concerned with sustainability compared with younger workers. Thus, the variations in age and experience among this workforce group provide us with a rich tapestry of how energy supply interruptions are likely to be viewed and understood. Table 4.1 provides a breakdown of the age profile of the participants.

Table 4.1: Age profile of the participants

Frequencies for Age

Age	Frequency	Per cent	Valid Percent
45-54	15	30.000	30.000
35-44	16	32.000	32.000
44-54	7	14.000	14.000
25-34	6	12.000	12.000
55-64	3	6.000	6.000
45-50	3	6.000	6.000
Missing	0	0.000	
Total	50	100.000	

The majority of the participants recruited in the study are aged between 35-54 years, accounting for a combined 62 % of the total population. A total of 16 participants were in the 35-44 age group, followed by 15 participants in the 45-54 age bracket. The study's age demographics are in line with the overall outlook of the South African manufacturing sector, which is related to the beneficiation of minerals.

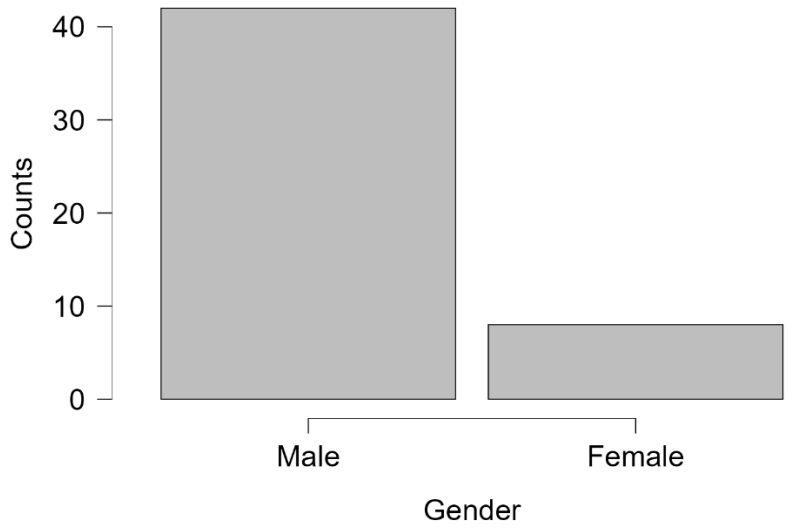
According to Statistics South Africa (2021), data shows that South Africa's manufacturing sector largely benefits from its younger working-age demographic. Most of the workers are between 25 and 34 years old, with the next largest group being those aged 35 to 44. This means that a good portion of the workforce in this sector is relatively young; however, the demographic shifts occurring in the country are affecting the sector as well. The population is ageing, and the share of older workers in the workforce is growing.

4.2.2 Gender

Analysing the role of gender in research is important because it greatly affects the results. Despite being largely a product of culture, gender influences not just the overall viewpoint of the people taking part in research but also their specific

perspectives (Halm, 2017). This is especially true when it comes to situations that males and females perceive differently. The graph Figure 4.1 below offers a presentation of the study's gender profile:

Figure 4.1: Gender profile of the participants



The table below, Table 4.2 provides the actual breakdown of the gender profile of the study participants:

Table 4.2: Frequencies for Gender

Gender	Frequency	Per cent
Male	42	84.000
Female	8	16.000
Missing	0	0.000
Total	50	100.000

A total of 84 per cent of the participants of the study were males and 16 per cent were females. This pattern is in line with the trends existing within the South African mining and manufacturing industries, which are male-dominated on the basis that the work required is heavy, dirty and riskier, generally not to the liking of females or that industry players prefer employing males. According to the Department of Trade and Industry

(2019), only around 24% of women in South Africa hold craft and trade positions within the manufacturing sector, indicating a significant gender gap in this industry.

4.2.3 Level of Education

Understanding the educational background of each participant was another goal of the study. This is essential for any study, but particularly for this study, which is based on the perspectives of the participants. One would argue, and it would also be fair to say, that when a research study has more educated participants, it will likely have more reliable and insightful data (Alali, 2024). Table 4.3 below shows the educational levels of the participants in the study:

Table 4.3: Frequencies for Education Level

Education Level	Frequency	Per cent
Diploma	12	24.000
Bachelors	31	62.000
Masters	3	6.000
Trade Test	4	8.000
Missing	0	0.000
Total	50	100.000

The participants boast a notable level of education, with 62% holding at least a Bachelor's degree. This suggests that most of the respondents possess a solid academic foundation and are likely to have the kind of analytical and technical skills that allow them to fully grasp the implications of an energy supply interruption. 24% of the participants possess a Diploma, something that not only puts them in the category of higher education but also suggests a level of vocational or technical training that might give them a degree of practical insight into some of the operational challenges being encountered at the smelter.

A small percentage, 6%, have a Master's degree. These are highly qualified individuals who may offer perspectives on policy, management, and strategic

interventions. Another 8% hold a Trade Test certification, reflecting their specialised technical expertise. The presence of such a diverse skill set among the participants is important for our study.

4.2.4 Job Title

The study also sought to understand the position of each of the participants' job titles at the Hillside Smelter. Table 4.4 provides the job title frequencies.

Table 4.4 Frequencies for Job Title

Job title	Frequency	Percent	Valid Percent	Cumulative Percent
Process Supervisor	1	2.000	2.000	2.000
Operation Superintendent	1	2.000	2.000	4.000
Supervisor	1	2.000	2.000	6.000
Maintenance Supervisor	16	32.000	32.000	38.000
Process Control Engineer	4	8.000	8.000	46.000
Process Specialists	8	16.000	16.000	62.000
Maintenance Superintendent	1	2.000	2.000	64.000
Maintenance Coordinator	1	2.000	2.000	66.000
Systems Engineer	3	6.000	6.000	72.000
Project Manager	3	6.000	6.000	78.000
Project Engineer	3	6.000	6.000	84.000
Maintenance Engineer	4	8.000	8.000	92.000
Process Engineer	4	8.000	8.000	100.000
Missing	0	0.000		

Job title	Frequency	Percent	Valid Percent	Cumulative Percent
Total	50	100.000		

The study had its participants drawn from various departments within Hillside Smelter's 15 divisions. The position that attracted the most participants was the maintenance supervisor, which had 16 respondents. Due to the existence of many units within the smelter plant, the business requires many maintenance personnel to ensure that work is done effectively. The study also recruited engineers, superintendents, and project managers among other positions. One critical aspect to note is that the study had fewer administrative employees, but rather people who work hands-on with the machines on the ground every day, who deal with the energy supply interruptions.

4.3 Data Findings

This section sets the tone for the presentation of data through descriptive statistics and themes, methods that are well-suited for mixed-methods research (Braun & Clarke, 2012). The study gathered data from 50 participants through a questionnaire that provided the opportunity to appreciate both statistical and short narrative answers from the participants. The study made use of two data analysis tools: the JASP software for descriptive statistics and the NVivo tool for identification of themes from the short narrative responses from the questionnaire.

Themes reflect a general idea that captures the views and perceptions of the participants. The study assigned identity codes to the participants ranging from Participants 1-50, and in some cases, the participants will be referred to as P with the number. The data will be presented in a manner that entails the use of both quantitative and qualitative data in a complementary way, wherever possible and applicable.

4.4 Impact Assessment

Section B of the questionnaire (see attached Appendix A) was focused on meeting the first objective of the research, which focused on establishing the social, environmental, and financial impact of energy supply interruptions on the Richards Bay smelter.

4.4.1 Social Impact

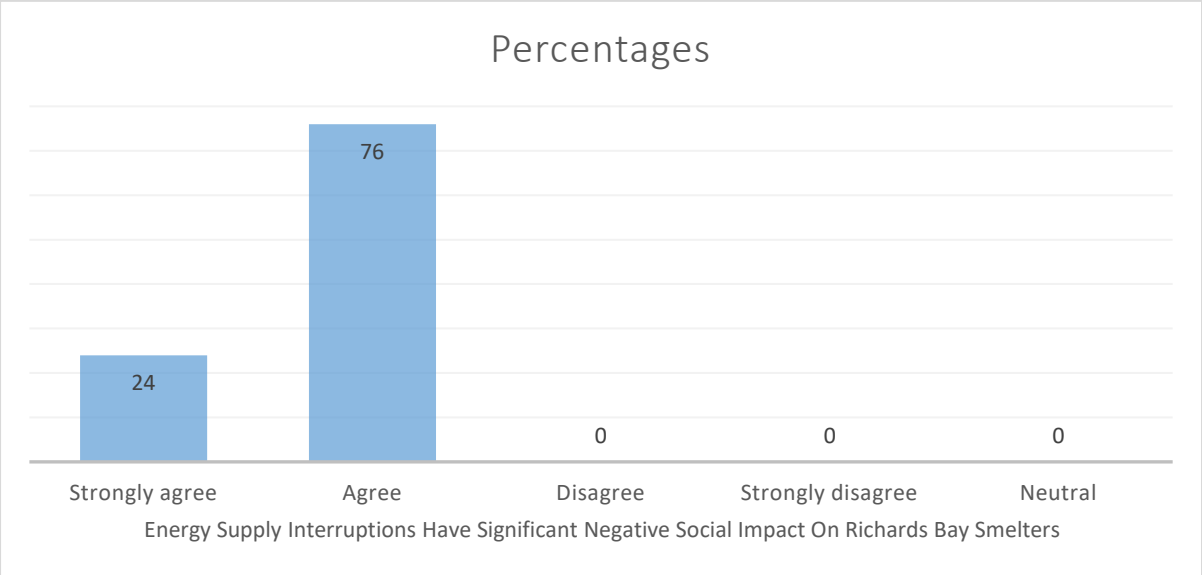
Question 1 of Section B assessed whether energy supply interruptions have a significant negative impact on the social environment of the Richards Bay Smelter. The majority of participants believe that interruptions in energy supply negatively affect the social environment of the Richards Bay smelter. An impressive 76% agree, while another 24% strongly agree, that these interruptions affect social dynamics (Table 4.4).

Not a single participant disagreed with the impact of electricity interruption on the social impact. This strong consensus is a clear indication that participants in the study believe the workforce, community relations, and the social stability of the smelter are severely impacted. On top of that, there were no missing responses, so every participant had something to say about this issue, making the data all the more reliable. Table 4.4 below provides the frequencies for energy supply interruptions.

Table 4.4 Frequencies for energy supply interruptions have a significant negative social impact on the Richards Bay smelter.

Energy supply interruptions have a significant negative social impact on the Richards Bay smelter.	Frequency	Per cent	Valid Percent
Strongly Agree	12	24.000	24.000
Agree	38	76.000	76.000
Missing	0	0.000	
Total	50	100.000	

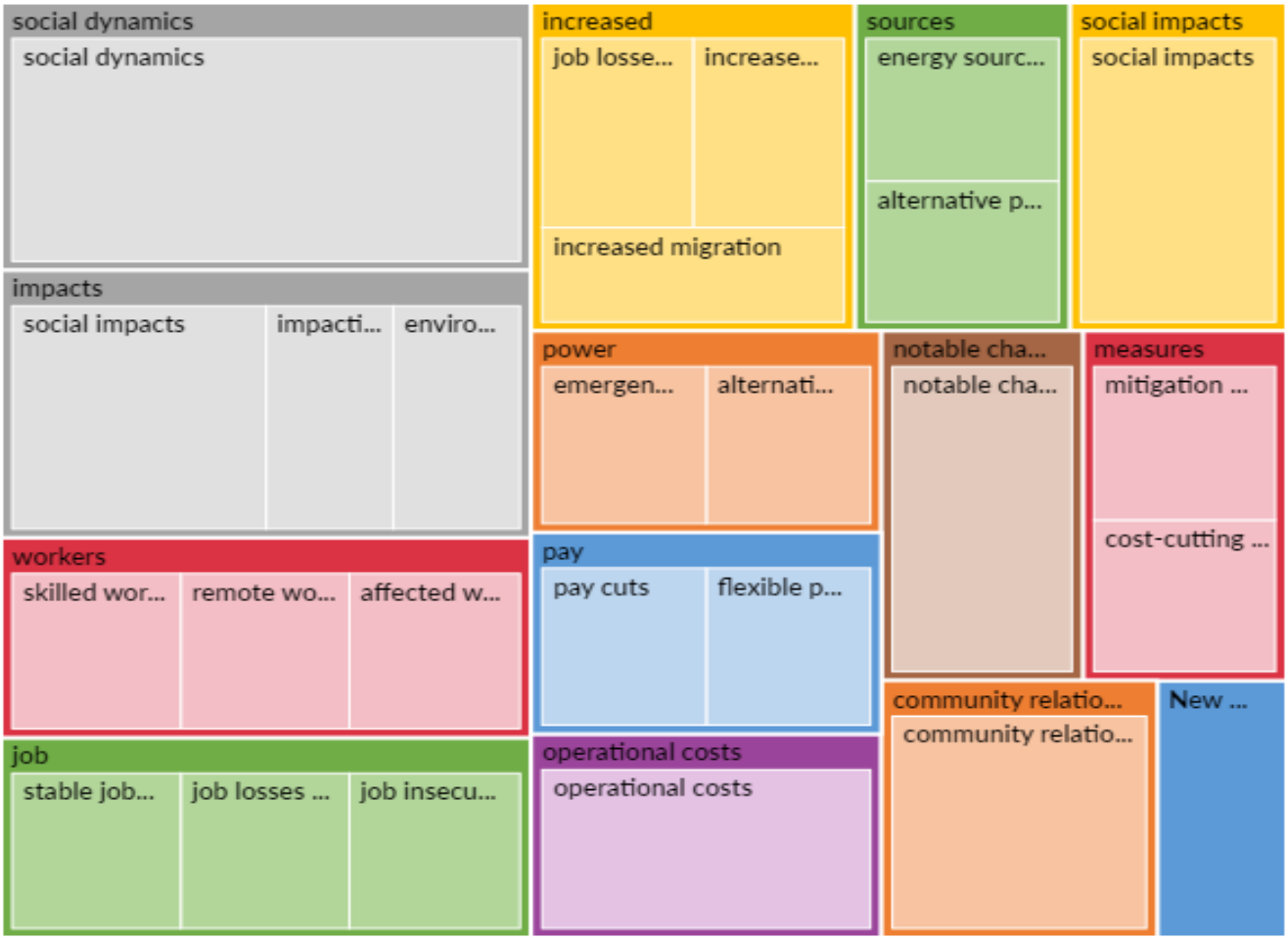
Figure 4.2: Frequencies for energy supply interruptions have a significant negative impact on the social environment of the Richards Bay smelter



The consensus on the harmful social effects of power interruptions could be tied to the multiple hurdles that the employees and their community face. Frequent power outages can result in job losses because of reduced productivity, with companies using the excuse of cutting costs to lay off workers. From a thematic aspect, the social impact was the first theme in the hierarchy of themes from the NVivo tool under the social dynamics and social impact themes. Moreover, frequent power supply has harmed socio-economic activities such as small businesses that create direct and indirect jobs.

The image below displays the main concepts derived from the NVivo data analysis. The themes have been organised into different facets like societal interactions, effects, workforce, job permanence, remuneration, running expenses, authority, and actions to lessen impacts. The figure underscores particular worries around employment reductions, population shifts, and the sources of energy. It speaks to the societal toll along with the financial pressures from measures like pay cuts and cost-cutting. It also explores community relations, significant changes, and the kinds of alternative power solutions being considered. The figure wraps all this in a storyline that hints at the social, economic, and environmental toll of the phenomenon being studied. Figure 4.3 provides the themes identified by the NVivo analysis.

Figure 4.3: NVivo Themes



Participant 5 had this to say:

> *"Crime rate and job losses increase."*

This view is supported by Participant 17, who responded as follows:

> *"Workers face pay cuts, leading to increased financial stress and conflicts at home."*

In a broader community context, these interruptions can damage the very fabric of relationships between businesses, employees, and the local stakeholders. An essential element in these relationships is trust, and when businesses are seen as fundamentally unable to provide a stable, non-dysfunctional work environment for their

employees, no amount of pay or benefits seems to compensate for that loss. Employees in these kinds of communities cannot easily pick up and move somewhere else on the basis that they are essentially bound to the local economy, and when it takes a hit, they feel the pain, too. So do their families.

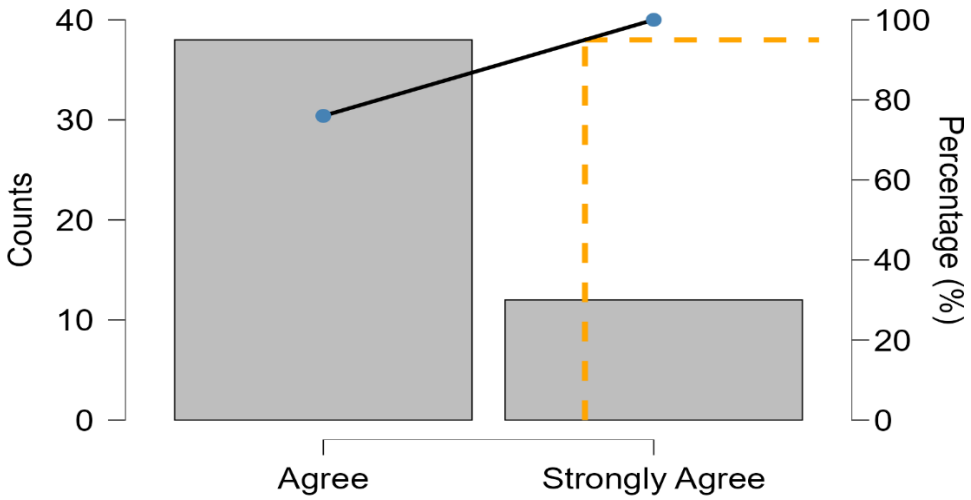
A further significant outcome of these findings is the likelihood of labour disputes and associated declines in workforce morale. Workers who repeatedly confront uncertain and unstable work environments lose motivation. They also lose confidence in their employer's ability to provide for them and to keep conditions running smoothly, such that their shifts can proceed in the energy-intensive job of making metal. This is especially true in the case of prolonged instability. Not only does this sap morale and lead to poorer individual performance it also destroys relationships between workers and their management.

This view is supported by Participant 43, who stated the following:

> *"Employees experience job insecurity, leading to higher turnover rates."*

Figure 4.4 provides the responses of the participants on social and environment impact.

Figure 4.4: Energy supply interruptions have a significant negative impact on the social environment of the Richards Bay smelter.



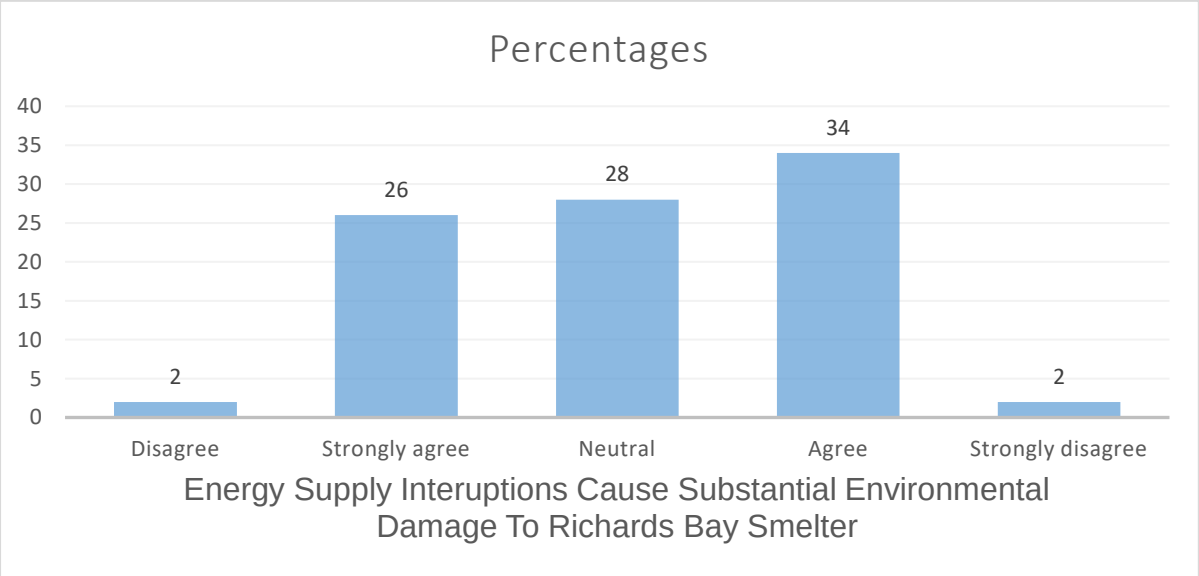
ons have a significant negative impact on the social environment

The graph above presents severe issues impacting both the workforce and community, with unanimous acknowledgement from respondents on the negative social effects due to interruptions in energy supply. The level of agreement seen in the responses underscores the urgent need for attention to this matter. If leaders focus on solving the energy supply puzzle, and what it provides to the smelter, they will likely also be ensuring for the workforce not just better pay and working conditions which can lead to more money flowing to local businesses but also the principles of trust, fairness, and respect that can sustain a stable workforce in a smelter and a stable social environment in a local community.

4.4.2 Environmental Impact

Section B also sought to find the impact of energy interruptions on the environment. The study appreciated the following data patterns from the responses of the participants represented in the table below. Figure 4.5 provides a breakdown.

Figure 4.5: Frequency for Energy Supply Interruptions



The data refers to differing perspectives on how much energy supply interruptions cause damage to the environment at the Richards Bay smelter. Most surveyed either “Agree” (34%) or “Strongly Agree” (26%) with the idea that energy interruptions cause

massive environmental damage, forming a 60% consensus. Meanwhile, not a few (28%) marked down “Neutral,” conveying a measure of doubt or absence of clear, first-hand knowledge regarding the connection between energy interruptions and environmental harm. The data about opinions on energy interruptions was stark: 60% of respondents agreed that substantial damage occurs, while only 4% disagreed.

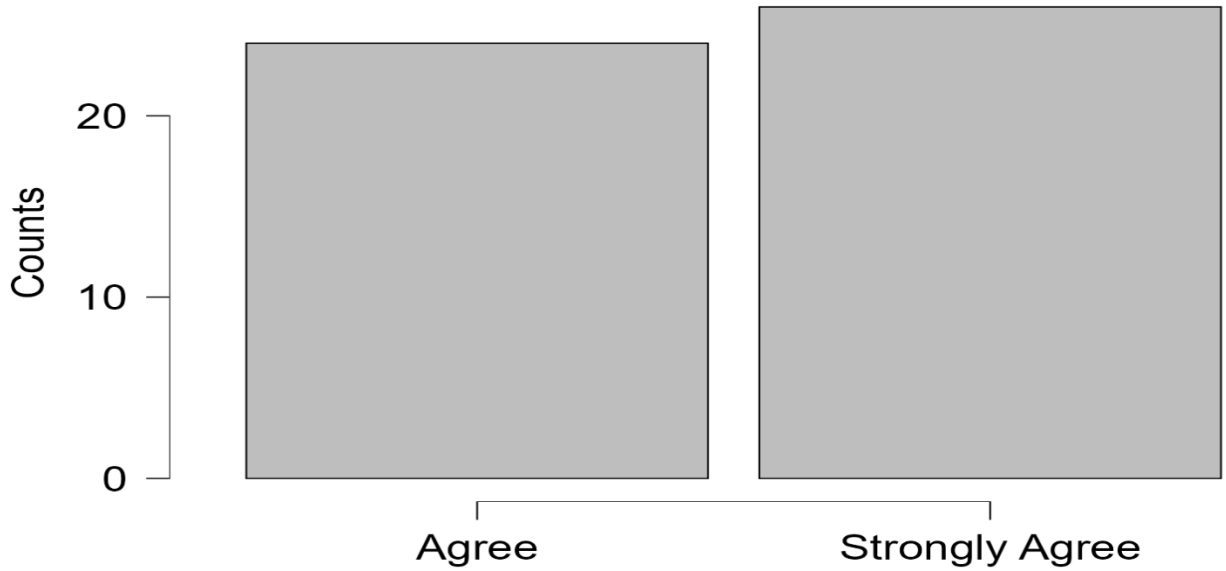
Industrial energy supply interruptions, such as those at the Richards Bay smelter, have a broad range of environmental impacts. In an industrial setting, the types of pollution control systems that typically suffer during a power outage include gas treatment centres (GTCs) and dust filtration units (Alexander et al., 2018). Without adequate power, systems like those can release a bunch of harmful emissions into the atmosphere, like sulphur dioxide, carbon monoxide, and a lot of other nasty stuff, along with particulate matter.

While the data offers significant insights, various factors could shape respondents' perspectives, leading to potential biases. To begin with, participants' awareness and expertise levels likely differ, affecting their ability to perceive and understand environmental consequences directly and immediately. Undoubtedly, employees with some kind of responsibility for handling environmental issues have much better-formed perceptions of the relationship between power interruptions and environmental harm than employees in other roles, such as those in human resources or perhaps even in more direct production roles.

4.4.3 Financial Impact

From a financial aspect, all participants shared the same view, as shown by the table below. The financial impact of energy supply interruptions is the most significant concern for the Richards Bay smelter. The information highlights a shared understanding among the 50 survey participants of the hefty toll that energy supply disruptions take on finances. Everyone agrees some more intensely than others on the magnitude of this threat and not a single person was on the neutral option. The greater part of the group (52%) strongly agrees, underscoring the idea that energy interruptions do not make small dents in finances; they make big ones and are possibly the top concern among operational challenges. Figure 4.6 provides the financial impact on energy interruptions.

Figure 4.6 Financial impact of energy supply interruptions is the most significant concern for the Richards Bay smelter.



act of energy supply interruptions is the most significant concern

Table 4.5 below provides the breakdown on the responses of the participants regarding the financial impact of energy supply interruptions.

Table 4.5: Frequencies for the financial impact of energy supply interruptions are the most significant concern for the Richards Bay smelter.

The financial impact of energy supply interruptions is the most significant concern for the Richards Bay smelter.	Frequency	Percent
Agree	24	48.000
Strongly Agree	26	52.000
Missing	0	0.000
Total	50	100.000

A chief takeaway from this is the serious financial vulnerability of the smelting operations. In effect, smelters need a constant and large energy supply to keep their production processes going (Tabereaux, 2023). Any kind of interruption in that supply

can be costly and can throw into chaos not just the basics of getting and staying online but also significant aspects of what might be called an "energy rhythm" that defines a smelter's work life.

From a qualitative aspect, terms such as losses and operational costs were common in the responses of the participants. The picture below provides proof of the appearance of the terms as observed by the NVivo tool.

Figure 4.7: NVivo Word Tree



Participant 12 supports the assertion above by stating the following;

> *"Heavy financial losses, forcing the company to revise expansion plans."*

The reliability of the energy supply makes up what seems to be a foundational aspect of financial stability for the kinds of operations that these folks are running. Participant 33 echoed the same sentiments and stated the following;

> *"Implementing cost-cutting measures and negotiating with suppliers for flexible payment terms."*

The study identified the numerous factors that lead to the financial impact outcomes of energy supply interruptions at the Richards Bay Smelter from both the responses of the participants and the existing literature. Among the most significant are:

a. Production losses

The core of any smelting operation is a high-temperature process, and restarting this process after an energy supply interruption is no easy task. What usually happens is a prolonged downtime, a period when the facility is not producing anything, and that is very costly financially (Pérez et al., 2021).

b. Equipment damage

When the power goes off suddenly, it affects the mechanical aspect of the operation of the machines, which have a fixed module and patterns they have to follow, either in starting or switching off and abrupt absence of energy therefore affects their effectiveness and potentially causes damage and malfunctioning that is expensive to fix. It can also ruin your machines.

c. Increased operational cost

The smelter, if affected by an energy supply interruption, has very few options except to turn to alternative power sources, generally some kind of diesel turbine. Using such a "Plan B" makes the smelter's operation a lot more expensive (Pérez et al., 2021).

d. Reputation as a cost multiplier

Smelters and their principals operate in a world of webs and networks, mainly comprising supply chains and procurement agreements. The extent to which they function as the cornerstone of a reputational economy is underappreciated and gravely underestimated, as the failure to meet agreed deadlines has a bearing on the reputation of the entity for future orders.

4.4.4 Section Summary

This section underscores the deep social, environmental, and economic consequences of energy supply failures at the Richards Bay smelter. The evidence

clearly shows that these failures have major effects on the stability of the workforce and the well-being of employees. All the respondents in the survey seemed to agree that the effects on the workforce and community are so serious that they constitute a crisis. The power outage is likely to lead to job losses in the thousands and cause significant financial stress to the workforce, which in turn will affect community morale.

From an environmental angle, there's a broad agreement, though not as strong as a consensus (60%) on the adverse impacts of energy supply interruptions. A fair number of respondents (more than a third) took no stand on this issue. This suggests that they might not have a clear sense of what happens to the environment when the power goes out. Nonetheless, industrial research confirms that when energy fails, systems meant to control pollution are not able to do their job, leading to more emissions, which can in turn create environmental dangers.

The financial lens through which we view the data indicates that the smelter's biggest worry is the stability of its energy supply. Without energy, nothing works. One hundred per cent of respondents in the study said that when there's an energy interruption, there are huge financial implications for the smelter. When there is no power, the smelter stops producing, and that alone is a big loss. But a power cut also damages equipment and costs a fortune to repair, and it further hurts the smelter's reputation. Ultimately, the study highlights just how important it is to have a dependable energy supply if the smelter is to maintain any sort of social, environmental, or economic well-being.

4.5 Mitigation Measures

Section C of the questionnaire focused on understanding and appreciating ways to lessen the social, financial, and environmental impacts that energy supply interruptions have on Richards Bay Smelter. Given the gravity of the situation highlighted in the preceding sections, this part of the survey sought to uncover potential strategies that could minimise the negative effects of energy instability on the smelter's operations.

The questionnaire provided possible mitigation measures and using a Lickert scale sought to understand the level of agreement or disagreement thereof on the part of

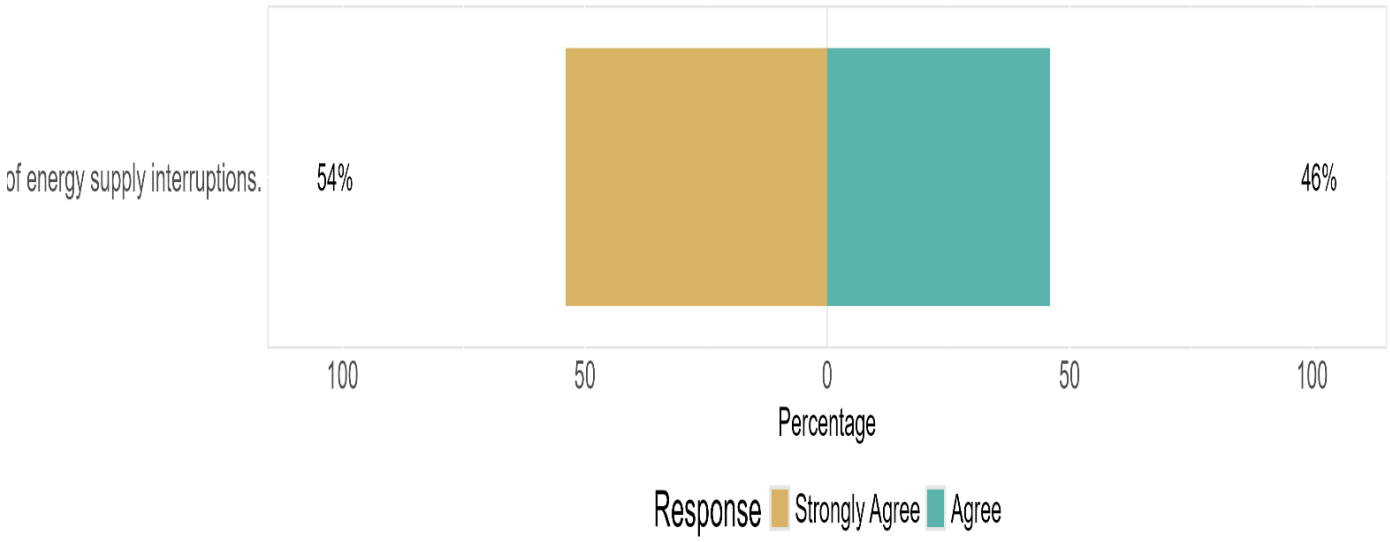
the participants in implementing such a mitigatory measure. The questionnaire cited the following mitigatory measures:

- Backup energy to deal with the social impact of energy interruptions.
- Investing in renewable energy to deal with the environmental impact.
- Establishing contingency funds for mitigating the financial losses caused by energy supply interruptions.
- Improving energy infrastructure resilience for minimising the social, financial, and environmental impacts.
- Collaborating with local communities and government agencies for effective mitigation of energy supply interruptions.

4.5.1 Backup

Regarding putting up a backup system, the responses of the participants are captured on the graph below. The results depicted in the table reveal a unanimous agreement among participants on the effectiveness of deploying alternative energy sources as a countermeasure against the social upheaval that energy supply interruptions seem to generate at the Richards Bay Smelter. All respondents 100% either "Strongly Agree" (54%) or "Agree" (46%) with the notion that using alternative energy is a legitimate and effective way to pre-emptively deal with the energy supply shortages that have all too frequently plagued the smelter over the recent past. Figure 4.8 provides a breakdown of the participant responses on mitigation measures.

Figure 4.8: Frequencies for Implementing Backup Energy Sources is an effective mitigation measure for reducing the social impact of energy supply interruptions



This data highlights the use of alternative energy as a pre-emptive approach to lessen interruptions that might affect workers and the nearby community. Frequent power supply issues are associated with job loss, a reduction in direct income, and an increase in social tensions, as seen in the previous round of responses. Ensuring operational continuity through alternative energy sources could directly and positively affect the livelihood of workers and the well-being of the community (Naidoo, 2023). The strong agreement among participants is a testament to the recognition of the very palpable benefits that this power source reaps.

Furthermore, the survey highlights that employees and other stakeholders have experienced the social consequences that accompany power disruptions and that these have made an indelible impression on the collective psyche. The use of emergency power sources like generators or alternative power solutions is not just essential for maintaining the operation of key systems but also for keeping canteens, worker accommodations, and other vital infrastructure running in the absence of a regular power supply. In other words, maintaining a stable energy supply is seen as key to maintaining workforce morale and a potentially high level of energy.

This view is further proved by the following short narrative responses by the participants. Participant 45 stated thus;

> *"The use of backup is crucial in keeping our workstations functional during outages"*

Participant 33 had this to say;

> *"Implementing reliable alternative energy solutions is necessary to protect both employment stability and community well-being"*

Participant 22 responded as follows;

> *"Alternative energy backups are one of the ways to keep things stable."*

The findings are in step with larger trends in industrial risk management, especially within the context of South Africa, which is seeing increased investments in alternative energy sources as back-ups for the sake of improving operational efficiency (Akinbami, Oke & Bodunrin, 2021; Naidoo, 2023).

4.5.2 Investing in Renewable Energy

Table 4.6 below provides a breakdown of the responses of the participants regarding their views on the smelter investing in renewable energy.

Table 4.6: Frequencies for investing in renewable energy sources is a viable solution to mitigate the environmental impact of energy supply interruptions.

Investing in renewable energy sources is a viable solution to mitigate the environmental impact of energy supply interruptions.	Frequency	Per cent
Strongly Agree	27	54.000
Agree	17	34.000
Disagree	3	6.000
Neutral	3	6.000
Missing	0	0.000

Table 4.6: Frequencies for investing in renewable energy sources is a viable solution to mitigate the environmental impact of energy supply interruptions.

Investing in renewable energy sources is a viable solution to mitigate the environmental impact of energy supply interruptions.	Frequency	Per cent
Total	50	100.000

The respondents largely back the idea of investing in renewables as a solution to disruptions in energy supply. The survey shows that 54% of participants strongly agree and 34% agree, making for a very solid 88% endorsement of the idea. Still, a portion of the respondents, 6%, disagreed; another 6% took a neutral stance. This suggests that, while most participants view the idea favourably, a not-insignificant minority either question it outright or have their doubts.

The participants' expression of faith in renewable energy is encouraging. It is believed to have the potential to mitigate the environmental effects that come with energy supply disruptions. Renewable energy sources, such as solar, wind, and hydropower, are essentially cleaner forms of energy when compared to fossil fuels. The generally optimistic view is that renewable energy can help in the diversification of industrial energy sources. However, the 12% of respondents who disagree or remain neutral deserve some attention. Their doubts could spring from at least two major concerns. First, there’s the cost issue specifically, the capital investment needed to integrate renewable energy into existing structures.

Renewable energy often requires hefty upfront spending, and some stakeholders could be wondering if the long-term environmental advantages would truly be worth these kinds of expenses. Secondly, there's the matter of reliability and scalability. By their very nature, renewable energy sources depend on natural conditions. This is a technical problem that, unless solved, could make some respondents very leery about relying on renewables for the kind of heavy lifting that industrial operations demand.

The dissenting voices might also come from a place of limited awareness or experience with renewables. In settings where traditional energy has long been the

go-to, the idea of switching to something more sustainable might just not be widely accepted yet. This inertia of sorts is likely even more pronounced when one considers that, for many, the transition to renewables is still in its "proof of concept" phase in some respects. While a healthy number of participants have endorsed the idea, the neutral responses being fairly close to one-fifth of the total suggest that for some, the concept of energy substitution is still in its embryonic stage.

To sum up, although most participants solidly support the investment in renewables, a minority remain unconvinced, with some outright opposing and others sitting on the fence. Their concerns are worth noting for at least three reasons. First, renewables bring with them significant upfront costs, which could be a source of unease when it comes to justifying their use in place of traditional energy sources. Second, the reliability of renewables is a potential issue, given that they are less predictable than fossil fuels. And third, there is the scalability issue; can renewables generate enough power to not only replace what's being lost from traditional sources but also to meet the needs of a growing population?

4.5.3 Establishing Contingency Funds

Table 4.7 shows differing opinions on the idea that contingency funds are crucial for lessening the financial blows from interruptions in energy supply. A minority (2 per cent) of respondents strongly agree with the proposition, and 40 per cent more simply agree, putting a total of 42 per cent in the column of those who think contingency funds are an important tool for handling the financial losses of energy supply interruptions. Meanwhile, a sizable group of respondents (36 per cent) chose a neutral stance, and 22 per cent disagreed, either in the moderate (12 per cent) or strong (10 per cent) sense, with the contingency fund idea (EPRI, 2009). This 22 per cent is an interesting detail because it shows that the opposition is also fairly large. Table 4.7 below provides a breakdown participants' responses regarding contingency funds.

Table 4.7: Frequencies for establishing contingency funds are essential for mitigating the financial losses caused by energy supply interruptions.

Establishing contingency funds is essential for mitigating the financial losses caused by energy supply interruptions.	Frequency	Per cent
Strongly Agree	1	2.000
Agree	20	40.000
Neutral	18	36.000
Disagree	6	12.000
Strongly Disagree	5	10.000
Missing	0	0.000
Total	50	100.000

When first looking at the table, the immediate observation is that the 42 per cent who agree seem to belong to a much larger group than those who do not. On the flip side, the very high number (36 per cent) of neutral responses might imply that a lot of participants are indifferent towards or unsure about the potential of using contingency funds as a way to shield against financial loss. This kind of response could also mean that participants do not have a direct experience with, or enough examples of, the successful use of such funds. The study suggests some possible reasons for this ambivalence: Participants in the study might work in industries where operational costs are so high that any kind of financial buffer is insufficient to make up for the loss incurred when energy is interrupted

The split in opinions highlights a possible need for more dialogue and analysis concerning financial risk management in energy-intensive sectors. Although setting up contingency funds is a valuable way to safeguard against risk, it cannot be the only strategy and must be coupled with investments in technology and infrastructure as well as with advocacy for policy changes that might make the energy-intensive sectors more diverse in their energy mix. Contingency funds only address immediate financial

losses, but the combination of technology, infrastructure, and policy can attack both the symptoms and the causes of energy supply interruptions.

To conclude, even though some respondents favour the creation of contingency funds as a basic step to stem financial losses, a large group remains uncertain or even outright opposed to the idea. This divergence of views suggests the complexity of the problem and the need to consider the establishment of financial buffers in a more holistic framework.

4.5.4 Improving Energy Infrastructure Resilience

Energy infrastructure resilience is defined as the ability of energy systems, such as power grids, pipelines, and renewable energy sources, to endure, adapt to, and recover from disruptions caused by natural catastrophes, technological failures, or supply chain disruptions (Ahmadi, Saboohi & Vakili, 2021).

In the context of this study, resilience is critical for providing a consistent and dependable energy supply while reducing negative social, financial, and environmental consequences. A more robust energy infrastructure can reduce employment losses, avert financial instability, and mitigate environmental damage caused by supply disruptions. Table 4.8 below provides the breakdown of the responses of the participants to the question:

Table 4.8: Frequencies for Improving Energy Infrastructure Resilience is crucial for minimising the social, financial, and environmental impacts of energy supply interruptions.

Improving energy infrastructure resilience is crucial for minimising the social, financial, and environmental impacts of energy supply interruptions.	Frequency	Per cent
Disagree	13	26.000

Table 4.8: Frequencies for Improving Energy Infrastructure Resilience is crucial for minimising the social, financial, and environmental impacts of energy supply interruptions.

Improving energy infrastructure resilience is crucial for minimising the social, financial, and environmental impacts of energy supply interruptions.	Frequency	Per cent
Neutral	11	22.000
Agree	22	44.000
Strongly Agree	3	6.000
Missing	1	2.000
Total	50	100.000

The importance of enhancing energy infrastructure to withstand interruptions is a point of significant agreement among a group of 50 respondents. About half of them believe that it is critical to ensure robust energy systems to minimise not only the direct operational impacts but also the various negative effects on community well-being and the environment that follow power outages.

Interestingly, though, about a quarter of the group seems to disagree with the idea, in their responses suggesting that either alternate solutions or existing measures might be adequate in addressing the impacts of energy supply interruptions. The notable third way of thinking among the group is neutrality, which may reflect a lack of sufficient information about the benefits of improving energy infrastructure resilience.

A mixed bag of opinions surfaces when it comes to energy infrastructure. Respondents to a survey are pretty evenly divided about what should be done and how. While half of them see the importance of improving the infrastructure as a way to protect everything from operations to communities and the environment, a quarter of them either don't see a problem or don't see a need for the solutions they're being offered.

Another quarter of respondents are stuck in the middle, seeing no benefit and no harm. This diverse array of opinions probably reflects the very different kinds of experiences people are having with energy management, experiences that vary a lot depending on what kind of role they're in.

A small amount, just 2% of missing data, does not significantly affect the trustworthiness of these results. Looking at the cumulative percentages, one can see a logical progression of agreement levels. Nearly half of the respondents are in favour of using energy infrastructure improvements to reduce the impacts of energy disruptions. This means decision-makers and stakeholders can have confidence in the level of support for these kinds of projects. But it also means they need to think about how to bring the dissenters around to their point of view. Or, at the very least, to understand why it's necessary to do energy infrastructure improvements.

Improving energy infrastructure is vital to counteract the varied impacts of energy supply interruptions. Investing in projects that enhance the reliability and resilience of energy systems will pay off in terms of operational continuity, reduced financial losses, and minimised harm to the environment. For those who are sceptical or neutral about these types of projects, it's worth engaging in transparent dialogue.

4.5.5 Collaborating with Local Communities and Government

Collaboration with local communities and government agencies refers to the active engagement and partnership of energy companies, municipalities, and the general public in addressing electricity supply interruption concerns (Dall-Orsoletta, Romero & Ferreira, 2022). This partnership entails exchanging information, coordinating reaction activities, and adopting collaborative plans to improve energy resilience.

In this study, teamwork is critical for limiting the detrimental effects of energy disruptions on sectors, enterprises, and homes. Local governments can work together to establish regulations that promote energy stability, and communities can help by adopting energy-efficient habits and sharing real-time feedback on outages. Table 4.9 provides a breakdown on the responses provided by participants regarding collaborations with local communities and government agencies.

Table 4.9: Frequencies for collaborating with local communities and government agencies is necessary for the effective mitigation of energy supply interruptions.

Collaborating with local communities and government agencies is necessary for effective mitigation of energy supply interruptions.	Frequency	Per cent
Strongly Disagree	2	4.000
Neutral	1	2.000
Strongly Agree	23	46.000
Agree	21	42.000
Disagree	3	6.000
Missing	0	0.000
Total	50	100.000

The findings show an overall agreement on the need to work with local communities and government agencies to diminish energy interruptions effectively. A combined 88% of respondents either strongly agree or agree with a collaborative approach (Table 4.8). This support suggests that stakeholders see energy supply issues as something more than just a technical problem to solve. They recognise that energy supply systems are part of a larger weave of social, political, and economic fabrics. And when those systems are threatened, our fabric of life is threatened too.

A large majority backing the collaboration strategy indicates that stakeholders view local communities and governmental entities as indispensable partners in tackling energy disruptions. These institutions frequently shoulder the responsibility for planning and maintaining critical infrastructure, which can also mean a significant investment of public and private dollars. They are the ones that majorly contribute to the emergency response systems, which are essential when it comes to energy crises.

In a business setting like that of the Hillside smelter, where energy reliability is crucial to production and operational efficiency, the collaboration of these two energy partners can pay dividends. Government agencies often provide not only regulatory support but also financial incentives. And when push comes to shove, one can rely on resilient local communities to ensure that essential services are maintained despite the crisis.

Nonetheless, the evidence indicates robust support for collaborative efforts, with only a small minority expressing reservations. Specifically, 6% of respondents disagreed, and an additional 4% strongly disagreed, with the statement, while 2% remained neutral (Table 4.8). These dissenting views could be partially explained by the concern for potential inefficiencies and bureaucratic challenges that can arise when a multitude of stakeholders is involved. For some, the collaborative process is simply too slow and cumbersome, especially when a rapid response is essential. There is also the possibility that some respondents have had bad experiences with collaborative efforts in past situations in which the "all-hands-on-deck" philosophy failed to produce tangible results or even led to muddled and gap-filled crisis management.

The existence of a minority dissent highlights the need not only to advocate for joint strategies but also to guarantee that they are organised in ways that make them efficient and effective. It is crucial to outline clearly the roles and responsibilities of each partner and to establish a means of working together that ensures rapid implementation during emergencies.

Additionally, for these partnerships to succeed, trust must be built and maintained. Trust can only be built through regular and effective communication, and it can only be maintained through the use of joint training exercises that ensure everyone is on the same page when it comes to any type of contingency planning (Dall-Orsoletta, Romero & Ferreira, 2022). The minority of respondents less convinced of the approach's efficacy can lend some credence to the idea that these strategies, when executed well, can indeed work.

Ultimately, the survey strongly endorses the idea of working with local communities and governments to handle energy supply issues. The vast majority favour this action, and it's easy to see why: such partnerships have multiple potential benefits. Not only do they bring together the various skill sets and resources of different groups,

enhancing the ability to problem-solve and implement solutions, but they also mean more people have a stake in the outcome.

4.5.6 Section Summary

Survey results show a strong agreement on several steps aimed at reducing the social, financial, and environmental effects of energy supply problems at the Richards Bay Smelter. Every surveyed person supported using alternative energy sources, such as backup generators, to keep things running when the power goes down. This means that almost all of them saw those alternatives as an essential way to avoid the wide range of adverse effects when energy interruptions occur (Metz & Cardell, 2023).

Nearly everyone also endorsed the idea of using renewables to supply some of the power that the smelter needs, though some people worry about the costs and the reliability of these renewable sources. Only the use of contingency funds got a reaction close to 50-50 in terms of approval or disapproval. What the data from this survey most clearly shows is that people see the problem of energy supply at the smelter as something needing substantial, proactive solutions (Linares, 2008). Revamping the resilience of the energy infrastructure received an average level of support (63 %), a higher percentage than any of the other options offered in the survey.

4.6 Extent and Magnitude Assessment

The thrust of this section is premised on the need to combine insights from the questionnaire's section D to thoroughly appraise the reach and heft of the social, environmental, and financial impacts of energy supply interruptions at the Richards Bay smelter.

The core aim of the study is directly addressed in this section through the integration of quantitative survey data and rich qualitative accounts, and it provides a much more comprehensive understanding of how these interruptions affect not just the operational aspects of the smelter's work but also the wider community and ecological systems.

Two aspects are key under this section: the frequency of the energy interruptions and the severity of the impacts they have on the social, financial and environmental aspects.

4.6.1 Frequency and Recovery Time of Energy Interruptions

The survey sought to find how frequency of the occurrence of energy interruptions and how long it takes to recover. According to the statistics, the recovery time at Richards Bay Smelter varies after an interruption in the electricity supply. The majority of responders (26%) claimed that the smelter recovers in less than a day, while 24% suggested a recovery time of 1-2 weeks. Furthermore, 22% of respondents claimed that full recovery takes more than two weeks, while 16% reported a recovery time of one to two days. A tiny fraction (2%) said that recovery takes 3-5 days, whereas 10% reported that disruptions happen regularly. These findings illustrate the possible operational delays induced by energy supply outages, as well as the various levels of resilience during the recovery process. Table 4.10 below provides a detailed breakdown of the two aspects and how related they are:

Table 4.10 Frequency of Energy Supply Interruptions and Recovery Time at Richards Bay Smelter

Recovery Time After an Energy Supply Interruption	Frequency	Percentage (%)
Less than a day	13	26.00%
1-2 days	8	16.00%
1-2 weeks	12	24.00%
More than 2 weeks	11	22.00%
3-5 days	1	2.00%
Frequently	5	10.00%
Total	**50**	**100.00%**

The data reveals a remarkably consistent trend at the Richards Bay Smelter between the number of times the energy supply is interrupted and the related time to recovery. Respondents have provided for each category of frequency of interruption a recovery time that is the same as the reported frequency. For instance, energy supply interruptions that happen in "Less than a Day" are recovered in "Less than a Day."

Interruptions that happen "1-2 Weeks" or "More than 2 Weeks" take a recovery period of, respectively, "1-2 Weeks" and "More than 2 Weeks." Likewise, supply interruptions that occur "1-2 days" are covered over in "1-2 days" of recovery time. The lone response under "Frequently" indicates a recovery time of "3-5 Days." This way of looking at the data, with one-to-one correspondence, might lead one to perceive that the respondents, in general, view the recovery process as directly proportional to the frequency or perhaps the duration of the energy supply interruption itself. Indeed, this could be seen as a well-calibrated supply recovery process.

Yet, an in-depth examination of these results uncovers several problems with their methodology and interpretation. The perfect overlap seen between the frequency of interruptions and their recovery times might be a sign that something is wrong with either the way the survey was designed or the way the respondents understood the questions. In a practical sense, there might be no real breakdown in operations between the occurrence of an interruption and the recovery from it. So, the appearance of a "perfect" mirror image between these two could be more about the bias in the responses than about any real distinction between the interruption and the recovery that follows it. And while this would be of some concern, even more worrisome is the thought that all of this might be happening because of a framing effect and not just because of response bias.

From an operational perspective, the findings indicate that the recovery times at the smelter are not variable but are fixed to the kind of interruption experienced. This can be taken as a sign of a well-organised and predictable recovery protocol. However, it might also obscure problems that lurk below the surface. If the recovery process is inherently tied to the length of the interruption rather than the complexity of the underlying issue, this could indicate that the smelter’s contingency planning is reactive rather than proactive. The consistency of the responses might also suggest that the respondents lack a nuanced understanding of the recovery process. Or perhaps what we are seeing here is an institutional culture in which recovery time is standardised and the reasons for the interruption are ignored or otherwise made irrelevant.

In summary, the data shows a seemingly straightforward connection between how often power is interrupted in the Richards Bay Smelter and how quickly operations there can return to normal. Moreover, it suggests that this relationship holds across

brief and fairly straightforward interruptions as well as longer and more complex outages. Despite this, the fact that the speed of recovery seems to be directly correlated with the type of interruption might signal something about the survey design that is influencing the way the respondents answer the questions.

4.6.2 Severity of the Impacts

Having established the frequency and recovery aspects of the smelter, the study sought to understand how participants view the severity of the impact from social, environmental and financial impact aspects. According to the statistics, most respondents consider the societal consequences of electricity supply disruptions at Richards Bay Smelter to be quite serious. The majority (76%) classified the societal impact as Very Severe, with 16% describing it as Extremely Severe. Only a small minority rated the impact as Moderately Severe (6%) or Slightly Severe (2%). These data indicate that energy interruptions have a substantial impact on social dynamics, most likely affecting workers, communities, and overall social well-being.

Table 4.11 below provides a critical breakdown on the severity of the impacts.

Table 4.11: Frequency of Participant Responses on Severity of the Impacts

Severity Level	**Frequency**	**Percentage (%)**
Slightly Severe	1	2
Moderately Severe	3	6
Very Severe	38	76
Extremely Severe	8	16
Total	**50**	**100.00%**

The frequency tables provide a crucial understanding of the serious consequences of energy supply interruptions at the Richards Bay smelter, touching upon social, environmental, and financial aspects. They reveal that, by and large, the participants in the study are inclined to consider the social and environmental consequences of power supply disruptions as severe to extremely severe. The social impact, for instance, was seen as very severe by 58.33% of the respondents, and as extremely severe by 33.33%; the environmental impact, meanwhile, was seen as very severe by

88.57% of the respondents, and as extremely severe by 11.43%. The financial impact, as mentioned, was rated by most respondents as either extremely severe (66.67%) or very severe (33.33%). These ratings across the board suggest that energy supply disruptions are viewed as profoundly bad and are likely to lead to several ominous occurrences.

Likewise, participants also rated the environmental consequences of energy interruptions as very severe. A substantial 88.57% of respondents in one of the relevant categories rated the environmental impact as very severe, while 11.43% rated it as extremely severe. Interruptions in the energy supply are likely to lead to some environmental degradation, including increased emissions from backup power sources. Moreover, the very severe rating given by the respondents suggests that even minor interruptions are likely to cause a ripple effect in terms of operational efficiency and ecological harm. On the other hand, another category in the survey showed 100% of respondents rating the environmental impact as moderately severe, which may suggest that there is some variability in how different groups from within the smelter experience these energy supply interruptions.

Energy supply interruptions are perceived to have a very significant impact on the smelter's finances. Two-thirds of respondents (66.67%) rated the financial impact as extremely severe, and another group of 45.71% of respondents assessed it as very severe. Additionally, 31.43% believed that these interruptions were very frequent. Across all three groups, none of the participants rated the financial impact as minimal or non-existent. This suggests a common view that the plant’s financial vulnerability to an energy supply interruption is not only severe but also very present. Interestingly, a large minority (14.29%) of respondents in one group opined that the financial impact was rare, which might explain some of the variation in interpretations seen across the financial severity table.

A fascinating observation is that no respondents believed the financial impact occurred almost constantly, yet a full 100% of one group believed it to happen frequently. This indicates that while energy interruptions may not happen every day, their effects are long-lasting when they do occur. No one in any part of the financial severity table chose

the occasional or rare columns. In those sections where frequent or constant were picked by some, the absence of occasional or rare adds weight to the judgments of the respondents who marked those categories. Even though no one chose constant in any of the five tables, a good number of respondents in some categories picked the frequent column.

These results underscore the importance of enhancing the energy infrastructure's resilience at the smelter. The overall social, environmental, and financial impacts are so severe that immediate and long-term solutions need to be found. These might include investments in renewable energy, strategic collaborations with energy providers, or the adoption of energy-efficient technologies. The scale of the problem at the smelter, an operation that uses a tremendous amount of electricity, demands that management find a way to feasibly and effectively protect their operations, their workforces, and their bottom lines with energy security.

4.7 Comparison of Literature Review and Own Findings

RQ #	**State Research Question or Objective**	**Prop/hyp #**	**State Proposition or Hypothesis** (literature review response to RQ)	**Findings from own study**
1	What are the social, environmental and financial impacts of energy supply interruptions on the Richards Bay smelter?	1	Interruptions in energy supply wield substantial influence over several key dimensions of contemporary society: social stability, environmental sustainability, and the financial viability of industrial operations.	Participants in the study unanimously recognised (100% agreement) the severe economic hit from power failures, citing the loss of production and the increase in running costs as the most serious concerns. Socially, the main issues identified

RQ #	State Research Question or Objective	Prop/hyp #	State Proposition or Hypothesis (literature review response to RQ)	Findings from own study
			Energy is life, and when it is abruptly curtailed, lives are affected, sometimes adversely and a large scale. The social impacts of energy supply interruptions are well-known: they cause immediate and lasting job losses, stress, and lower morale. The environmental impacts are equally significant: they lead to increased emissions and pollution, largely because "unregulated" releases become a default operating mode when energy is not available.	by the study as related to power failures are job insecurity and low morale, which lead to financial distress among workers. From an environmental standpoint, 60% of participants agreed that power failures cause severe harm, mainly because they lead to unfiltered emissions.
2	What are the effects and impact thereof of the mitigation	2	The literature highlights alternative energy solutions,	The research revealed that everyone backed using reserve power

RQ #	State Research Question or Objective	Prop/hyp #	State Proposition or Hypothesis (literature review response to RQ)	Findings from own study
	measures undertaken to deal with the social, environmental and financial implications of energy supply interruptions on Richards Bay smelter?		investments in green power, emergency funds, robust infrastructure, and teamwork among stakeholders as effective ways to reduce the risks of climate change. These methods have varying degrees of effectiveness, depending on the industrial context and the specific risks involved.	as a highly effective way to cut emissions. Eighty-eight per cent said renewable energy is a good investment and a potential job creator. However, many expressed concerns about the cost and reliability of renewables. Only 42% thought setting up a contingency fund was a good idea, reflecting a pretty conspicuous level of doubt about whether it could be done. Rebuilding power plants and other infrastructure to make them more resilient in the face of climate change had the support of 50% of those surveyed and was opposed by 26%. Collaboration among various stakeholders was widely seen as a

RQ #	State Research Question or Objective	Prop/hyp #	State Proposition or Hypothesis (literature review response to RQ)	Findings from own study
				good idea, garnering 88% support.
3	What mitigation measures can be proposed to address the social, financial and environmental impacts of energy supply interruptions on the Richards Bay smelter?	3	Literature advocates for increased investment in renewable energy, strengthening grid resilience, creating contingency funds, implementing demand-side energy management, and fostering collaboration with government and local communities.	The study suggests five main strategies for mitigation: investing in renewable energy, reinforcing the sturdiness of infrastructures, establishing reserve funds for emergencies, managing energy demand on the user side, and increasing cooperation among interested parties. The study's recommendations are not all that different from what one might find in recent literature sources, but they do emphasise the involvement of local stakeholders and the use of financial support mechanisms.

4.8 Chapter Summary

The chapter discussed the data from both quantitative and qualitative aspects based on the responses provided by the participants on the questionnaire. The study would provide the response accounts given by the participants to show the basis of the discussion of the major findings. The chapter also sought to confirm the findings and views of the participants with those of other studies and scholars. The next chapter presents the climax point of the study by providing a conclusive position of the study.

CHAPTER 5

DISCUSSION OF FINDINGS

5.1 Introduction

This chapter aims to lay out definitive conclusions and suggestions stemming from the findings unearthed by this specific investigation. As needed, the work of presenting insights using a thematic approach and a range of descriptive statistics was carried out in the previous chapter. The act of concluding will be fundamentally rooted in the results obtained there. This section will also direct relevant stakeholders to the kinds of changes that might be made to enhance the study's case of the social, environmental and financial impact of energy supply interruption in Richards Bay smelter.

5.2 Research Question 1 Discussion

What are the social, environmental and financial impacts of energy supply interruptions on Richards Bay smelter?

The research question sought to establish the social, environmental and financial impacts of energy supply interruptions on Richards Bay smelter. The study findings reflect the three aspects that the study was very much interested in.

5.2.1. Social Impact

From a social aspect, energy interruptions cause major disruptions in the workplace and community. All respondents in a recent survey said these interruptions lead to job losses, decreased morale, and financial instability. This is consistent with Banda's (2020) study focusing on Lusaka's Kalingalinga Township, in which the study established that frequent power outages there have caused a spike in the unemployment rate and also in social distress and crime. The social impact can be seen in the case of South Africa, where small and medium-sized businesses experience high levels of psychosocial stress during times of "load shedding" as reported by Banderker (2022).

Most existing research looks at the general workforce and how energy interruption affects them, but the current study shines a light on how smelter workers in particular suffer from job insecurity. It takes the existing literature a step further by showing that the industry-specific vulnerabilities are the crux of the matter. As energy interruptions are mostly examined in situations where the jobs are informal or in service sectors, smelter jobs in an industrial setting where the work is both skilled and technical seem to be the last frontier of job and income security.

5.2.2 Environmental Impact

From an environmental standpoint, a significant number of participants (60%) concur that energy stoppages lead to heightened emissions, primarily because they allow for unregulated releases from pollution control systems that have malfunctioned. This finding is strongly supported by the research of Belelie et al. (2019), who concluded that Eskom's unstable power supply has led to increased emissions in numerous South African industrial areas. Even more recently, Bird, von Gruenewaldt, and Petzer (2022) have shown evidence that power stoppages in the Dolphin Coast and Richards Bay areas lead to a reliance on alternative energy sources like diesel generators that are more polluting than the power plants (which now have state-of-the-art environmental controls) they replace.

There seems to be a gap, however, between this study and previous ones such as Bird, von Gruenewaldt, and Petzer (2022) when it comes to environmental awareness. The existing literature focuses on the effects of large-scale pollution. In contrast, this study found that 28% of respondents were neutral when asked about the environmental impacts of power outages. The data here is suggestive and points to a continuing need for environmental education in the energy sector especially at the worker level.

5.2.3 Financial Impact

The study identified the financial consequences of energy disruptions, with unanimous agreement among respondents about the severe economic impact. Production losses heightened operational costs, and damaged reputations figured prominently as financial problems. These results are in line with research by Erero (2023), who

applied a computable general equilibrium (CGE) model to show how power outages in South Africa lead to cuts in industrial output and affect GDP. Similarly, du Venage (2020) described the effects of Eskom's failures on South African business finances, with firms either temporarily suspending operations or, in some cases, closing down for good.

An intriguing point of difference seems to lie in how the costs are recouped. Work by An and Mikhaylov (2020) found that Russian investments in South Africa's energy sector served to keep industry supplied with electricity and prevent the economy from taking too many hits. The current research, though, finds that smelters remain as exposed as ever in the wake of energy interruptions and that the financial instruments devised are not resoundingly tried and true. This is a clear gap between the toolkit of theoretical policy interventions and the deployment of workable solutions.

5.3 Research Question 2 Discussion

What are the effects and impact thereof of the mitigation measures undertaken to deal with the social, environmental and financial implications of energy supply interruptions on Richards Bay smelter?

The interruptions to the energy supply at Richards Bay Smelter result in considerable impacts across social, environmental, and financial dimensions. Hence, a variety of interventions have been examined to mitigate their effects. These measures are aimed at minimising the losses in production, reducing environmental harm, and alleviating the workforce inconveniences that arise from the energy supply issues. This study sought to evaluate such interventions to assess their impact.

5.3.1 Backup Energy Solutions

The research participants showed unanimous agreement on using alternative energy to counteract societal disruptions. This mirrors the work of Mabunda (2021), who emphasised the role of solar energy in curbing the stoppage of South African industry during power outages. Backups, however, as the study demonstrates, cannot always replace the high-energy operations that are needed for full production.

5.3.2 Renewable Energy Investments

Renewable energy was a favoured option, with a significant majority (88%) backing investments in power sources like solar and wind. This level of support aligns with what Hochstetler (2020) discovered in their research: that renewable energy is playing an ever-larger part in South Africa's industrial resilience. However, the cost and reliability of renewables remain serious concerns. These are the same 88% who are unaware or are simply ignoring the arguments that people like Adefarati and Bansal (2019) have put forth. Such scholars and others working in the field have said that the public does not seem to understand that even when they are used as microgrids, renewables require a very large initial investment.

5.3.3 Contingency Funds

Contingency funds, as a mitigation measure, garnered just 42% support, reflecting doubt about their practicality. This goes against what Inglesi-Lotz (2023) posits: that financial buffers are essential for shielding businesses from the economic jolts of load shedding. The difference might be in the industries, though the financial buffer might work for smaller businesses. The energy-intensive and capital-reliant smelting industry is an entirely different setup, and the capital required is intensive.

5.3.4 Infrastructure Resilience and Stakeholder Collaboration

About 50% of those surveyed were in favour of bolstering the energy infrastructure. However, 26% opposed it based on how expensive it is. These results appear to complement the study by Cha (2020), who contended that investments in energy resilience are hampered by political and financial hurdles, even when their long-term value is obvious. Participants surveyed seemed to think the answer lay in collaboration: 88% endorsed working with governments and local communities, something that Dall-Orsoletta, Romero, and Ferreira (2022) say is necessary for any system of joint governance.

5.4 Research Question 3 Discussion

What mitigation measures can be proposed to address the social, financial and environmental impacts of energy supply interruptions on Richards Bay smelter?

The study looked into various short-term and long-term strategies used to reduce the serious social, financial, and environmental effects of energy supply disruptions. Several potential energy supply solutions were provided by the participants. Below is the critical discussion for each proposed aspect:

5.4.1 Renewable Energy Integration

The findings suggest that the smelter should speed up its shift to renewable energy. Adefarati and Bansal (2019) emphasise how economical hybrid renewable systems are, and they mention that a combination of solar and wind energy, along with battery storage, could stabilise the energy needs of the smelter. Even though these systems have a high initial cost, their long-term benefits outweigh that cost. These benefits come not only in the form of keeping the smelter supplied with the energy it needs but also in the form of reduced dependence on the Eskom grid, which has become quite unreliable.

5.4.2 Strengthening Infrastructure and Demand-Side Management

Renovating grid systems and introducing advanced energy management can enhance dependability. According to Erero (2023), bringing in demand-side energy management like load shifting is a pathway to making industries use energy optimally. This study backs up that premise, finding that half the respondents (50%) in the study sample supported the idea of investing in resilient infrastructure.

5.4.3 Stakeholder Engagement and Policy Advocacy

Working more closely with government and energy providers is essential. The overwhelming 88% agreement among respondents on the critical importance of stakeholder engagement indicates that recent policy initiatives, which aim to stabilise the industrial energy supply and achieve some semblance of energy justice, are widely seen as necessary.

5.5 Conclusion

The research section on discussion of findings validated that when the energy supply to the Richards Bay smelter is cut off, it leads to dire consequences across multiple

fronts social, environmental, and financial. Socially, it tends to result in significant job losses and inordinate levels of financial stress on the smelter's operations. The environmental toll generally sees a marked increase in emissions, which are released in a largely uncontrolled manner, given the nature of the smelting process. Financially, it puts the smelter at a sizable risk not just of the already enumerated production losses but also in terms of ballooning costs.

CHAPTER 6

CONCLUSIONS & RECOMMENDATIONS

6.1 Introduction

The chapter concludes the study by putting together key insights about the social, environmental, and financial impacts that stem from interruptions to the energy supply at the Richards Bay smelter. It further discusses how effective the existing countermeasures are and what the actionable solutions might be in order to deal with the situation. It suggests recommendations and areas of further study.

6.2 Research Question 1 Conclusion

The investigation reveals that energy supply disruptions profoundly affect the Richards Bay smelter in three core areas: social, environmental, and financial. The societal consequences are particularly severe, with job losses, financial instability, and diminished morale among workers being the central concerns. The research directly links power outages with increased unemployment, reinforcing findings from previous studies in similar contexts, such as the one by Banda (2020) that looked at Lusaka's Kalingalinga Township. However, unlike prior research, the current study sharply underscores the plight of workers in a context where power outages happen with increasing frequency, showing that the workers face an employment situation that is anything but secure.

Power disruptions not only cause inconvenience but also harm the environment by increasing emissions and pollution. This is because they often lead to the failure of pollution control technologies and the use of more polluting alternative energy sources,

such as diesel generators. Belelie et al. (2019) and Bird et al. (2022) have demonstrated that the same sorts of environmental degradations occur in the industrial areas they studied. Despite this, the study found an interesting and potentially dangerous discrepancy in environmental awareness: while the literature has focused on power cuts leading to macro-level pollution, a large minority (28 percent) of the study's respondents said they were unaware of any environmental consequences of power cuts (e.g., pollution or emissions).

Financially, energy interruptions lead to significant losses for companies, as well as increased costs due to the need to maintain backup systems. These effects are substantial, as indicated by the numbers in the study, which are analysed by Erero (2023) and du Venage (2020) and which Erero (2023) and du Venage (2020) elaborate on in the cited works. They are not just large, but also direct costs to the companies affected, which then have to recover those losses somehow. However, the mechanisms for recovering these costs are where the study's findings diverge most starkly from those in the literature, especially concerning foreign energy investments and smelters. The smelters in this study remain highly vulnerable and are, presumably, at great financial risk. Therefore, in this instance, the study offers up both a more nuanced understanding of what energy interruptions mean financially for companies and a call to action for better cost recovery mechanisms and financial risk management offerings in the energy investment sector.

6.3 Research Question 2 Conclusion

The study indicates that measures to reduce energy supply issues at the Richards Bay Smelter have had different levels of success. Essential backup power systems are uniformly seen as a way to cut down the number of times workers have to stop what they are doing due to power outages. Still, these systems cannot keep all the parts of the smelting plant operating at full load. Prior research, like that of Mabunda (2021), underscores the promise of solar energy in keeping operations from grinding to a halt across industries. But this particular research, for the first time, takes a close look at the unique problems facing smelters, the high-energy operations, and the replacement of intensive energy uses, most notably the smelter itself. The second is the sheer size of the problem when it comes to using conventional generators as a backup energy source.

In terms of long-term solutions, renewable energy stands out, as 88% of respondents have shown a preference for it. This underscores Hochstetler's (2020) contention regarding the increasing role of renewable energy in ensuring the kind of industrial robustness needed to support our economic growth. Renewables like solar and wind have become cost-effective underpinnings for industry and society. Yet our findings diverge from much of the literature in that they point to a significant amount of scepticism that exists within the industry; the long-term costs and payoffs of renewables are not well understood, especially when it comes to their installation and maintenance over traditional forms of energy, a point highlighted by Adefarati and Bansal (2019), which the industry seems to regard as a safer bet. Smelting is an energy-intensive process that is not going to see a massive shift to renewables as the sole source of energy anytime soon.

A significant difference is the low support for contingency funds, with only 42% of participants backing them. This stands in contrast to Inglesi-Lotz (2023), who strongly advocated for their role in mitigating economic risks. This could be due to the large energy demands of smelting; while financial safety nets may suffice for small businesses, the capital-intensive nature of smelting makes them an inadequate standalone strategy.

On the other hand, the endorsement of infrastructure resilience and the fairly high support for government and community collaboration (88%), a defence against energy interruptions, allows the study to understand why Dall-Orsoletta et al. (2022) argue so fervently for the cooperative governance of such projects. Therefore, this study does much to carry the understanding of energy resilience forward, especially in terms of the ways that industry-specific conditions shape the preferences of key stakeholders.

6.4 Recommendations

The study offers five key recommendations to lessen the social, environmental, and financial effects of energy supply interruptions at the Richards Bay Smelter. Each of these recommendations has been carefully evaluated in terms of viability and likely success. Below is a breakdown of these ideas and what makes them promising:

6.4.1 Investment in Renewable Energy Sources

A large portion of the participants advocated for renewable energy investments as a long-term fix for energy supply interruptions. This makes a lot of sense because of the environmental and financial effects of energy supply failures. To keep the lights on, the smelters need to integrate renewable energy sources, such as solar and wind power, into their energy mix. These renewable sources, according to some estimates, could provide a significant portion, perhaps even upward of 50 per cent, of the energy these smelters need to operate.

In a world where energy crises are increasingly frequent, the smelters would do well to adopt energy security plans at least as robust as those found in other industrial sectors. Many other industries have already pioneered the relatively simple solution of integrating renewable energy into their work processes. This is because it pays off in the long run in terms of both cost and operational reliability.

Nonetheless, serious doubts linger about the intermittency of renewable energy. Yet these doubts could be dispelled by the use of hybrid systems that incorporate some form of energy storage. Of perhaps more significance is the presence of government incentives and policies that make investments in green energy attractive to the private sector. Government incentives could be used to cut the cost of installing anything from a pinwheel to a battery.

6.4.2 Strengthening Energy Infrastructure Resilience

The findings highlighted a key theme: the necessity for a more robust energy infrastructure. Half of those surveyed emphasised the importance of upgrading the current systems to ward off power disruptions. Advanced grid technology, combined with smart monitoring systems, would allow us to detect potential grid failures much earlier than we can now. If we had such technology and systems in place, we would be able to do far more to maintain the grid in a state of good repair. If a part of the grid did go down, for instance, the technology and systems would facilitate a far more rapid and robust response. Moreover, the use of microgrids (which is a component of the advanced grid technology many are thinking about) can allow for a kind of energy supply decentralisation.

The main problem with making all these changes is that they will cost a lot of money. And the power companies, investors, and consumers are understandably concerned about paying for them. To help solve this problem, a range of mechanisms has been proposed, including public-private partnerships (PPPs), which allow private companies to fund the kinds of improvements that many of our critical infrastructure systems need. In exchange, the private companies get to make a profit off the improvements, at least for a while.

6.4.3 Establishment of Contingency Funds

Energy supply disruptions have significant financial impacts, and it's advised to set up a buffer fund to absorb the kind of economic losses that accompany power failures. Contingency funds might be used for, among other things, short-term backup power generation, maintenance, and paying the wages of employees.

6.4.4 Implementation of Demand-Side Energy Management

To tackle energy supply issues, embracing demand-side energy management is a strategic and proactive decision. This involves optimising energy consumption patterns to reduce peak demand and enhance efficiency. It means investing in energy-efficient technologies and processes to minimise waste and maximise productivity.

Demand-side management techniques such as load shifting, conducting energy audits, and automating energy controls significantly improve the stability of a smelter's operations. By shifting some of the energy-consuming tasks to off-peak times, a smelter can save on energy costs.

6.4.5 Strengthening Stakeholder Collaboration and Policy Advocacy

The research underscores the imperative of working with local communities, government bodies, and stakeholders to ensure a steady flow of energy. The Richards Bay Smelter is recommended to develop even stronger partnerships with municipal authorities, energy regulators, and local businesses to make sure that the lights stay on. This is because energy is a fundamental building block of our lives, and the lights staying on is, at its most basic level, a measure of our success as a society. The smelter must focus on advocating for better policies, and it should team up with other

industrial groups and the like to push for reform that will ensure a stable energy supply. Reforming the current regulatory framework and lobbying for more government investment in infrastructure is not enough for this group.

6.5 Suggestions for Further Research

The study proposes the following three research areas:

a. ***Assessing the long-term viability of renewable energy in energy-intensive industries***

With worries about the dependability and expenses of renewable energy options, future investigations might consider the practicality of hybrid energy systems. These setups would merge renewable sources with the established grid and storage technologies. A study of this sort could delve into the economic consequences, efficiency compromises, and enduring viability of such models. The focus would be on smelting and similarly energy-intensive industries, where these questions are most pressing.

b. ***The socioeconomic impact of energy supply disruptions on local communities***

This study briefly addressed the workforce disruptions due to power outages, but could delve more into the effects of energy instability on the wider communities reliant on industrial operations. Economic displacement, changes in local business patterns, and shifts in the resilience strategies of communities would be rich areas to explore for a fuller understanding of how the smelter industry is affected by and is dealing with the challenges of energy supply interruptions.

c. ***Policy and governance strategies for energy resilience in industrial zones***

Amid various views on infrastructure resilience and stakeholder collaboration, a thorough investigation might delve into the policy structures necessary to improve energy security in industrial centres. This study could look at successful cases from other nations, suggest incentives for regulation, and pinpoint effective methods for encouraging the kind of teamwork among industries, governments, and local communities that seems to happen all too rarely in this country.

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Appendix A: Data Gathering Tool



My name is **Ntombozuko Willie (Student No: 2209895)**. I am undertaking research titled: ***Investigation of social, environmental and financial impact of energy supply interruption in Richard Bay smelter.*** It is my utmost request that you answer this questionnaire as accurately as possible.

Section A: Demographic Profile

Tick next to your answer

1. **Gender:**
   - Male
   - Female
   - Other (please specify)
2. **Age:**
   - Under 18
   - 18-24
   - 25-34
   - 35-44
   - 45-54
   - 55-64
   - 65 or above
3. **Education Level:**
   - Some College/Associate Degree
   - Bachelor's Degree
   - Master's Degree
   - Doctoral Degree
   - Other (please specify) ……..
4. **Title of Job Position**

   ……

Section B: Impact Assessment

Objective: To establish the social, environmental, and financial impact of energy supply interruptions on Richards Bay smelter.

1. **Energy supply interruptions have a significant negative impact on the social environment of Richards Bay smelter.**
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree
2. **Energy supply interruptions cause substantial environmental damage to Richards Bay smelter.**
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree
3. **Energy supply interruptions lead to considerable financial losses for Richards Bay smelter.**
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree
4. **The social impact of energy supply interruptions outweighs the environmental impact on Richards Bay smelter.**
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree
5. **The financial impact of energy supply interruptions is the most significant concern for Richards Bay smelter.**
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree
6. **On a scale of 1 to 5, how would you rate the impact of energy supply interruptions on employee morale and productivity at Richards Bay smelter (1 meaning less impact and 5 meaning high impact)**

- 1
- 2
- 3
- 4
- 5

7. **How many times in the past year have energy supply interruptions led to unintended environmental incidents (e.g., emissions beyond permitted levels, spillage) at Richards Bay smelter?**
   ……

8. ***What percentage of the smelter's total operational costs in the last financial year was attributed to losses and damages due to energy supply interruptions? ……***

Section C: Mitigation Measures

Objective: To come up with or establish mitigation measures to address the social, financial, and environmental impacts of energy supply interruptions on Richards Bay smelter.

1. **Implementing backup energy sources is an effective mitigation measure for reducing the social impact of energy supply interruptions.**
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree
2. **Investing in renewable energy sources is a viable solution to mitigate the environmental impact of energy supply interruptions.**
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree
3. **Establishing contingency funds is essential for mitigating the financial losses caused by energy supply interruptions.**
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree
4. **Improving energy infrastructure resilience is crucial for minimizing the social, financial, and environmental impacts of energy supply interruptions.**
   - Strongly Disagree
   - Disagree
   - Neutral

- Agree
- Strongly Agree

5. **Collaborating with local communities and government agencies is necessary for effective mitigation of energy supply interruptions.**
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree

Section D: Extent and Magnitude Assessment

Objective: Assess the extent and magnitude of the social, environmental, and financial implications of energy supply interruptions in Richards Bay smelter.

1. **Rate the overall severity of social impacts caused by energy supply interruptions in Richards Bay smelter.**
    - Not severe at all
    - Slightly severe
    - Moderately severe
    - Very severe
    - Extremely severe
2. **Rate the overall severity of environmental impacts caused by energy supply interruptions in Richards Bay smelter.**
    - Not severe at all
    - Slightly severe
    - Moderately severe
    - Very severe
    - Extremely severe
3. **Rate the overall severity of financial impacts caused by energy supply interruptions in Richards Bay smelter.**
    - Not severe at all
    - Slightly severe
    - Moderately severe
    - Very severe
    - Extremely severe
4. **How frequently do energy supply interruptions occur at Richards Bay smelter?**
    - Rarely
    - Occasionally
    - Frequently
    - Very frequently

- Almost constantly

5. **How long does it typically take for Richards Bay smelter to recover from an energy supply interruption?**
    - Less than a day
    - 1-2 days
    - 3-5 days
    - 1-2 weeks
    - More than 2 weeks
6. **On a scale of 1 to 5, how effective have the current mitigation measures (e.g., backup generators, load management strategies) been in minimising the impacts of energy supply interruptions? (1 = Not Likely, 5 = Highly Likely)**
    - 1
    - 2
    - 3
    - 4
    - 5

Section E

Short Narrative Questions

1. **Impact (Social, Financial & Environmental)**

a. Can you describe how energy supply interruptions affect the social dynamics within Richards Bay smelter?
b. What environmental consequences have been observed as a result of energy supply interruptions in Richards Bay smelter?
c. How do energy supply interruptions affect the financial performance of Richards Bay smelter?

2. **Mitigation Measures**

a. What strategies or initiatives have been implemented to mitigate the social impacts of energy supply interruptions?
b. What steps have been taken to minimise the environmental impact of energy supply interruptions?

c. How has Richards Bay smelter addressed the financial challenges posed by energy supply interruptions?

3. Extent & Magnitude

a. Have there been any notable changes in social dynamics or community relationships over time as a result of these interruptions?
b. From your perspective, what is the extent of environmental damage caused by energy supply interruptions?
c. In your opinion, how severe are the financial implications of energy supply interruptions for Richards Bay smelter?

Thank you for your time and participation

Appendix B: Consent Form





Sculpting global leaders

Informed Consent Form

Title of project:
Investigation of social, environmental and financial impact of energy supply interruption in Richard Bay smelter.

Name of researcher:
Ntombozuko Willie

I, Kevin Brooks....., agree to participate in this research project.

I agree to the following:

(Please circle the relevant options below)

The research study was explained to me. I understand what this study is about.	(YES)	NO
I understand that I can volunteer to take part in the study	(YES)	NO
I agree that the interview that may be audio recorded	(YES)	NO
I agree that direct quotations from my interview/focus group/other activity may be used by the researcher in their research report	(YES)	NO
I agree that my participation will remain anonymous (my name or other identifying data will not be used by the researcher in their research report)	(YES)	NO

I agree that other researchers may use the information I provide in my interview (depending on their own ethics clearance being obtained) but my name and any personal information will not be used or passed on

YES NO

..... (signature)
K. BROOKS (name of participant)
07/11/2024 (date)

..... (signature)
Ntombozuko Willie (name of researcher/person seeking consent)
06/11/2024 (date)

Appendix C: Participant Information Sheet



Dear Sir / Madam

My name is Ntombozuko Willie. I am a Masters student in the Master of Management in Energy Leadership at the University of the Witwatersrand, Johannesburg. My supervisor is Dr Silas K. Mulaudzi. I am conducting a research study about the impact of energy supply interruptions on smelter operations. The study title is: ***Investigation of social, environmental and financial impact of energy supply interruption in Richard Bay smelter***

I am inviting you to take part in an interview and answer a questionnaire on the impact of energy supply interruptions on smelter operations. If you decide to take part, your participation in this research study will last about 30 minutes, The interview will take place at South32 Hillside Aluminium boardroom office number ….at 09:30 am.

With your permission, I would like to audio record the interview. This data will be stored in my external HIKVISION drive for 5 years and deleted after 5 years. Only the researcher will have access to the data through having a security pin to open the files containing the recordings.

During the research activity, I will need to ask for some personal information about you, including your age, position, work experience, job description and views on the impact of energy supply interruptions on smelter operations.

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

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

The risks for this research study are no more than what happens in everyday life OR some of the questions asked may make you feel sad or upset. If this happens, I will stop the interview session and continue another time. If you need some support or counselling services following the interview session, these are available free of charge at Turning Point Mental Health Services. The name of the counsellor is Mrs. Mbali Mthembu Mensah and the contact details for the counselling service are 087 012 6176.

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

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

Yours sincerely,

Ntombozuko Willie
Researcher:
Ntombozuko ,ntombozuko.willie@students.wits.ac.za, 0713779025

Supervisor:
Dr Silas Mulaudzi, silas.mulaudzi@wits.ac.za, 0117173605

Appendix D: Ethical Clearance Certificate

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School

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

Ethics Clearance Certificate

Ethics protocol number: WBS/EL2209895/118
This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below).

Project title	Investigation of social, environmental and financial impact of energy supply interruption in Richard Bay smelter
Investigator / Researcher	Ms Ntombozuko Willie
Nature of Project	MM (Energy Leadership)
Decision of the Committee	Approved, provided stakeholders and participants are guaranteed confidentialty.
Issue Date of Certificate	21/11/2024
Expiry date	Date of submission of the project / research report
Chairperson	Dr Ayanda Magida ☎ +27 11 717 3953 ✉ ayanda.magida@wits.ac.za

Declaration by Researcher

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

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

Signature

19/12/2024
Date:

Appendix E: Permission to Undertake Research at Richards Bay Smelter

SOUTH32

Hillside Aluminium Proprietary Limited
9 West Central Arterial
Richards Bay, 3900
South Africa
T: +27 (0) 35 908 8111

www.south32.net

01 March 2024

To Calvin Mkhabela
9 West Central Arterial, Richards Bay, 3900, South Africa
P.O. Box 897, Richards Bay, 3900
Telephone : +27 35 908 8009
calvin.mkhabela@south32.net

REQUEST FOR PERMISSION TO CONDUCT RESEARCH :MASTERS OF MANAGEMENT IN ENERGY LEADERSHIP (MMEL) – RESEARCH REPORT MODULE BUSA 7481A

Dear Sir

I am Ntombozuko Willie company number 30001709 registered and a student for Master of Management in Energy Leadership at Wits Business School. I would Like to request that you allow me to conduct the required research report. The topic is **Investigation of Social, Environmental and Financial impact of Energy Supply interruption in Richards Bay Smelter** in your organization.

This is only required for academic purposes and will not be shared with any further parties. The information and the recommendations will only be seen by the lecturer, the external examiner, and the exams office. In addition, the information does not constitute a viable sample, but merely indicates a trend.

Your favorable response to this request will be highly appreciated.

Yours Sincerely

Ntombozuko Willie

Hillside Aluminium Vice President Operations

Calvin Mkhabela

Directors: KP Pillay (Chairman), CG Mkhabela, PM Mpepele, ZZ Ndandani
Company Secretary: South32 SA Limited

Registered Office: 9 West Central Arterial, Richards Bay, 3900, South Africa
Reg. No. 2001/004091/07

Appendix F: Certificate of Competence in Research Ethics



CERTIFICATE OF COMPETENCE IN RESEARCH ETHICS

Name: **Ntombozuko Willie**

Student No: **2209895**

Date of Certification: 16 July 2024- 15 July 2027 (This certificate is valid for a period of three years)

TRAINED BY:

PROF. JASPER KNIGHT

(RESEARCH ETHICS)

SIGNATURE:

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

This certificate is confirmation of successful completion of a training course in Research Ethics for Non-Medical human research, based upon achieving a minimum level of competence in different assessment tasks.

Appendix G: Proofreading Letter



08 July 2025

To the Research Supervisor

REF: Acknowledgement of Proofreading Editing

This letter serves to confirm and acknowledge that this research proposal titled, ***Investigation of social, environmental and financial impact of energy supply interruptions in Richards Bay smelter*** by, **Ntombozuko Willie** has been proofread and edited by LifeMark Consulting.

LifeMark Consulting has made all the necessary changes that improved the quality of this document.

Regards

Nkosi Magama

Sig.....

LIFEMARK CONSULTING
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