The challenges affecting South Africa's chrome smelters' sustainability

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DECLARATION

I hereby declare that the Mini-Dissertation submitted herewith to the North-West University in partial fulfilment of the requirements for the Master of Business Administration (MBA) degree is my own original work. It has been text-edited in accordance with professional communication standards and has not been previously submitted to any other institution for evaluation purposes.

Karabo Lawrence Mabuela

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I would like to express my gratitude and thank God for all the opportunities He has granted me in my life. Started by blessing me with loving and kind parents and grandparents, who have taught me to be compassionate and to treat others with respect.

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ABSTRACT

South Africa has the world's largest chromite reserves and is coupled with an installed ferrochrome smelting capacity of about 4,9 million tonnes per year. This available capacity has not been fully utilised as far back as 2006. This industry has come under severe pressure due to the high electricity tariffs and supply instability, intensifying global competition and stricter environmental regulations, including the introduction of a carbon tax. This study examines key challenges affecting the sustainability and growth potential of South Africa's chrome smelters, where sustainability is understood as the financial and operational viability required to maintain and expand smelting operations, as some of the ferrochrome smelting plants in South Africa have been shut down or operations halted over the past couple of years. Guided by a pragmatic worldview, a qualitative case study design was employed. Semi-structured interviews were conducted with seven purposively selected participants who are senior professionals occupying production, engineering, HSECQ, managerial and financial roles across South African ferrochrome smelters. Data were analysed using ATLAS.ti and adopted a grounded theory-informed thematic analysis. This approach yielded eight themes which are, (1) cost structure and economic pressures; (2) energy crisis, electricity tariffs and supply instability; (3) raw materials, logistics and infrastructure constraints; (4) global competition, China and ore export dynamics; (5) regulatory, environmental and HSEQ pressures; (6) technology, automation and skills; (7) stakeholders, communities and social licence to operate; and (8) strategic responses and recommendations.

The findings indicate that the sustainability of smelters is fundamentally affected by a cost-and-energy problem: electricity and raw materials dominate production costs, while load shedding and curtailment erode furnace stability and utilisation, pushing smelters high on the global cost curve. Global competition, particularly from Chinese smelters beneficiating chrome ore mainly from South Africa, and domestic ore-export and lack of special chrome ore pricing practices for local beneficiation have repositioned South Africa from a major to a marginal supplier and producer of ferrochrome. Environmental and carbon policies add significant costs but are not the primary root cause of unsustainability; rather, they amplify underlying energy, cost and logistics constraints. The study concludes that South Africa retains strong technical capabilities and proven technological routes; however, these strengths are constrained by capital limitations or investment appetite and by policy uncertainty. Sustainability, therefore, depends on coordinated interventions at company, industry, and policy levels, coupled with disciplined capital allocation, improved maintenance and reliability strategies, revised internal ore-pricing models for all vertically integrated companies, collaborative industry platforms, discounted electricity tariffs, frameworks, and coordinated beneficiation strategies and carbon policies. The research contributes an in-depth, practice-based understanding of how macro-level pressures manifest at the plant level in an energy-intensive, resource-based industry and offers empirically grounded recommendations to support more sustainable ferrochrome smelting in South Africa.

Keywords: Ferrochrome, sustainability challenges, electricity crisis, global competitiveness

LIST OF ABBREVIATIONS

CDM	Clean Development Mechanism
Eskom	Electricity Supply Commission
MWh	Megawatt-hour
NBI	National Business Initiative
RBM	Richards Bay Minerals
SiO2	Silicon dioxide
UNFCCC	United Nations Framework Convention on Climate Change
ICDA	International Chromium Development Association

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CHAPTER 1

1 Introduction

1.1 Introduction

South Africa's ferrochrome smelting industry remains strategically important to the national economy and downstream value chains; however, its sustainability and growth potential are increasingly constrained by structural pressures affecting cost competitiveness and operational continuity. This country's ferrochrome smelting capacity has remained stagnant since the early 2000's. South Africa went from the largest ferrochrome supplier in the world to being surpassed by China, which went from a marginal producer of ferrochrome in the early 2000's to being the major producer of Ferrochrome in the world. Ferrochrome industry analyses highlight persistent challenges in the local ferrochrome operating environment, including energy cost dynamics and broader industrial constraints (DTIC, 2020).

South Africa's ferrochrome smelting industry has faced intensifying sustainability pressures over the past decade, with cost competitiveness and operational continuity most affected by electricity-related constraints and broader market dynamics. Smelting is energy-intensive, with electricity requirements typically ranging from 3.31 to 3.63 MWh per tonne of ferrochrome produced, reinforcing the sector's sensitivity to tariff escalation and supply constraints (Pan, 2013). Electricity tariffs and associated regulatory determinations continue to shape the cost base of energy-intensive smelting operations. In parallel, logistics performance is another system-level constraint, with sector reporting indicating operational and volume pressures in the national rail environment (Transnet SOC Ltd., 2025). The export of chrome ore to China has been associated with a decline in South Africa's share of the global chrome smelting market, while China has expanded its ferrochrome output despite limited domestic chrome ore resources (Lotriet et al., 2023; Arnoldi, 2024). These challenges are significant because the ferrochrome industry contributes meaningfully to employment, export revenue, and broader industrial development in South Africa (Merafe Resources, 2012).

Within this context, the study investigates the challenges affecting the sustainability and growth potential of South Africa's chrome smelters, focusing on the organisational and external factors that influence strategic and operational decision-making. The chapter introduces the research context and rationale, presents the research problem, purpose and objectives, and clarifies the scope of the inquiry.

1.2 Definition List

- **CDM (Clean Development Mechanism)**

  A United Nations-run carbon offset programme under the Kyoto Protocol, enabling industrialised countries to invest in emission-reduction projects in developing nations in exchange for carbon credits (UNFCCC, 2025).

- **Cogeneration**

  The simultaneous production of electricity and useful thermal energy (e.g., steam) from a single fuel source, improving energy efficiency by capturing waste heat (IEA, 2022).

- **Decarbonisation**

  The process of reducing or eliminating carbon dioxide (CO_2) emissions from industrial processes, energy production, and other sectors, usually through renewable energy adoption, energy efficiency measures, or carbon capture technologies (IPCC, 2023).

- **Eskom (Electricity Supply Commission)**

  South Africa's state-owned electricity utility, responsible for generating approximately 90% of the country's power, primarily through coal-fired plants (Eskom, 2023).

- **Ferrochrome**

  An iron-chromium alloy (usually containing 50–70% chromium) used as a key raw material in stainless steel production, produced by smelting chromite ore (ICDA, 2025).

- **ICDA (International Chromium Development Association)**

  A global industry association representing chromium producers, users, and traders, offering market analysis and policy guidance (ICDA, 2025).

- **Load Shedding**

  The intentional, short-term shutdown of electricity supply to specific areas to avoid a complete grid collapse during times of inadequate generation capacity (Eskom, 2023).

- **MWh (Megawatt-hour)**

  A unit of energy equal to one megawatt (1 MW) of power used for one hour, often employed to measure electricity consumption or production (e.g., ferrochrome smelting consumes approximately 3.5 MWh per tonne of output).

- **NBI (National Business Initiative)**

  A South African coalition of businesses advocating for sustainable development, climate action, and policy reform, particularly in energy-intensive industries (NBI, 2023).

- **Net-Zero Emissions**

  A state where an entity's greenhouse gas emissions are balanced by removals (e.g., via carbon sequestration), resulting in no net addition to atmospheric CO_2 (IPCC, 2023).

- **SiO_2 (Silicon dioxide)**

A chemical compound (silica) found in chromite ore as an impurity; its removal during smelting increases energy and cost demands (USGS, 2023).

- **Smelting**
  A high-temperature metallurgical process to extract metal from its ore through chemical reduction (e.g., using coke to convert chromite ore into ferrochrome.
- **UNFCCC (United Nations Framework Convention on Climate Change)**
  An international treaty established in 1992 to combat climate change, with agreements such as the Kyoto Protocol and the Paris Agreement (UNFCCC, 2016).

1.3 Background to the study

South African chrome smelters have faced significant challenges over the past decade, mainly due to steep increases in electricity tariffs. Japie Fullard, the CEO of Glencore Alloys, has stated that the high tariffs charged to the industry have surged by over 500% in recent years and have led to a decline in the global ferrochrome market to 27% in 2011 from 39% in 2009 (Creamer, 2021).

Electricity tariffs increased by 653% from 2007 to 2022, while the country's inflation rose by only 129% over the same period. From 1988 to 2008, when South Africa's electricity crisis became evident, electricity tariffs increased but lagged behind inflation. This was due to Eskom's oversupply of electricity in the 1990s and government policy to keep electricity tariffs as low as possible to aid poor communities (Moolman, 2022).

When Eskom implements stage 4 load shedding, ferrochrome smelters must reduce their electricity consumption to 40%. They must switch off at least half of their furnaces and auxiliary plants, resulting in production losses. Ferrochrome smelters can venture into renewable energy to aid their struggles with high electricity tariffs and shortages. Adopting the proposed decarbonisation strategy outlined by the National Business Initiative (NBI) and implementing it urgently will put the industry in a better competitive position than it is now (National Business Initiative, 2023). Ferrochrome smelters need to minimise waste, recover as much chrome as possible, implement initiatives to improve energy and process efficiency, and adopt renewable energy.

Cogeneration plants can help smelters reduce their high electricity demand by using Carbon monoxide (CO) generated from submerged furnaces during production and reusing it to generate electricity. Cogeneration plants have also been used across diverse branches of the mining industry, including at Richards Bay Minerals (RBM). RBM operates furnaces to produce titania slag from ilmenite ore, and during that process, waste gas rich in carbon monoxide and hydrogen is generated. Waste gas, ordinarily flared into the atmosphere or used for on-site drying and heating, can be used in a cogeneration plant to produce electricity through an internal combustion engine (Schubert & Gottschling, 2011:146).

Cogeneration technology has been used sparingly in South Africa on a small scale; however, it has great potential to reduce electricity demand from Eskom, thereby alleviating electricity constraints (Schubert & Gottschling, 2011:148). Major smelters such as Glencore and Samancor have previously implemented small-scale cogeneration plants. Although prospective cogeneration projects at smelting facilities across the nation used to rely on receiving money from CDM carbon credits, current electricity costs and constraints should motivate smelting companies to place greater emphasis on implementing this technology on a larger scale. Glencore Alloys has undertaken to look more closely at this technology to assist in reducing reliance on Eskom (Creamer, 2021).

Electric energy that is required for ferrochrome production ranges from 3.31 to 3.63 MWh per ton of metal produced. The difference in electricity required is highly related to the Silicon Dioxide (SiO_2) content of chrome ores, which range from 4% to 20% (Pan, 2013). Renewable sources of electricity, such as wind turbines and solar farms, can be used as a substitute for electricity supplied by Eskom. This transition can be done in phases, depending on the availability of funds for implementation. In 2021, South Africa's ferrochrome industry announced plans to generate up to 750MW of electricity from wind, solar, and cogeneration plants by 2024 (Liedtke, 2021). The current status of these projects must be investigated, and whether they are still in the pipeline must be determined. This includes how many megawatts are expected from wind, solar, and cogeneration individually.

Decarbonising South Africa's heavy manufacturing sector is vital to ensure businesses remain profitable. South Africa is a middle-income developing country among the top 12 carbon-emitting countries, and ferroalloy production accounts for 11 Mt of those Carbon dioxide (CO_2) emissions. The heavy manufacturing sector's global competitiveness can be improved by decarbonising the industry towards the 2050 net-zero emissions target (National Business Initiative, 2023).

Decarbonisation initiatives of South African chrome smelters will not make the industry competitive in 2050, when it is expected that South Africa will have transitioned to a net-zero emissions economy in line with the Paris Agreement (UNFCCC, 2016). This transition must take place swiftly to ensure the survival of the South African chrome industry. The persistent high electricity tariffs charged by Eskom and the lack of a reliable electricity supply have led the industry to lose significant market share to China. This industry is heavily dependent on a cheaper, reliable electricity supply. As a result, a move towards alternative energy sources is critical to the sustainability of the South African chrome smelting industry. It is said that five of South Africa's ferrochrome smelters are already in a dire situation, having been shut down, liquidated, or placed under business rescue. The industry is worth rescuing because it is reported to contribute R41 Bn to South Africa's GDP, make R14 B payments to Eskom, and support 68000 jobs. In the past five years, the industry has had to shed direct employment of two thousand jobs, and losses are inevitable (Liedtke, 2021).

The export of chrome ore to China has also decreased the global market share of the South African chrome smelting industry (Lotriet et al., 2023). In this study, 'sustainability' refers to the financial and operational viability of South Africa's ferrochrome smelters. This operational and financial sustainability directly relates to growth potential: only when a smelter can maintain efficient and profitable operations is it positioned to expand or innovate. Therefore, throughout this proposal, the term' sustainability' will be used (encompassing growth potential) to emphasise the industry's ability to endure and prosper financially and operationally.

1.4 Purpose Statement

The purpose of this study is to examine the sustainability challenges faced by South Africa's ferrochrome smelting industry. It aims to understand the key factors limiting the industry's competitiveness and long-term viability, including energy constraints, regulatory pressures, and market dynamics, and propose strategies to address these challenges.

1.5 Problem Statement

The sustainability and growth potential of South Africa's ferrochrome smelters have been under significant threat over the past few years due to several challenges. South Africa's ferrochrome smelters have been losing much market share to China since 2004. South Africa has the largest reserves of chrome ore globally and was the major supplier of ferrochrome; however, since 2012, China has overtaken South Africa as the world's major ferrochrome producer. China was able to take South Africa's market share over time despite having no chrome ore reserves (Arnoldi, 2024). These challenges have arisen due to a combination of economic, environmental, regulatory, and operational factors for the chrome smelters. These challenges are critical because they threaten the SA chrome smelting industry, a cornerstone of South Africa's economy that contributes significantly to employment, export revenue, and industrial development (Merafe Resources, 2012). This problem is particularly pressing now as global market conditions fluctuate and environmental regulations become more stringent. The profitability of SA's chrome smelting industry is not guaranteed due to price fluctuations, and now more chrome ore is being exported from South Africa without value being added. The study will focus on chrome smelting operations within South Africa. Using a qualitative approach, involving semi-structured interviews with these stakeholders, the research aims to identify, explore, and understand these multifaceted challenges in detail. Failure to do so could lead to the decline of the chrome smelting industry, resulting in significant job losses and economic repercussions for regions dependent on mining activities. Addressing this gap in the literature is essential for developing strategies that can enhance the resilience and competitiveness of South Africa's chrome smelting industry. The problem being investigated in this study is the key challenges affecting the sustainability of South Africa's ferrochrome smelters, as more smelting operations are being suspended. This leads us to the following primary research question: "What are the key challenges affecting South Africa's ferrochrome smelters' sustainability and growth potential?".

1.6 Aim (Primary Objective)

The study aims to explore and describe the challenges affecting the sustainability and growth potential of South Africa's ferrochrome smelters.

1.7 Secondary Objectives

- To investigate typical challenges affecting smelters through a literature study
- To empirically investigate the specific challenges ferrochrome smelters experience
- To recommend actions to address these challenges.

1.8 Philosophical Assumptions

Pragmatism will be the best approach to finding a solution to the problem, as the sustainability of the ferrochrome industry in South Africa is complex and involves several factors. The reality is that South Africa's ferrochrome industry has been losing competitiveness in the global market over the past decade, and several challenges that have a significant influence on the industry's sustainability must be addressed. There are possible solutions to address most of those challenges, including high electricity costs, electricity availability, and competition from China, which has led to a high export of chrome ore (Liedtke, 2021).

Ontological assumptions are based on the fact that this industry does not exist in isolation but in a broader socio-economic and environmental context. The ferrochrome industry is influenced by a variety of factors, including the economic climate, social impacts, technological advancements, and environmental considerations, all of which are dynamic and interdependent.

Epistemological assumptions are based on knowledge acquired from the industry regarding its needs, power demand data, data on their own processes to optimise energy efficiency, employment figures, environmental impact studies, and industry collaborations. Knowledge from industry experts, economists and workers can provide viable solutions to address current problems.

1.9 Research Approach and Design

This study will employ a qualitative inquiry approach. The approach is to start the inquiry inductively, exploring the views of people in the chrome smelter industry. The qualitative approach is chosen because it allows for an in-depth exploration of the complex, multifaceted challenges facing South Africa's ferrochrome smelters. This method is especially suitable for understanding the subjective experiences, perceptions, and insights of industry stakeholders, which are essential for uncovering the nuances of sustainability and growth challenges. Using this approach enables the final report to be flexible in structure, considering the complexity of this situation. (Creswell, 2018, 51). This approach is instrumental in industrial research where stakeholders' experiences and perceptions are critical for understanding the broader implications of sustainability and growth challenges.

The study will utilise a case study design. This design aims to conduct a detailed examination of the chrome smelting industry in the South African context. Case studies are particularly effective for developing in-depth analyses and for capturing the complexities and contextual factors that influence the sustainability and growth potential of the industry (Stake, 1995; Yin, 2009, 2012, 2014).

Alternative approaches were considered. A mixed-methods design could strengthen the prioritisation or ranking of challenges; however, it was not adopted due to data access and time constraints, as well as the study's primary aim of generating rich explanatory insight. A quantitative approach was also considered; however, the challenge was data collection, as it would require access to sensitive company data, which could pose a risk to those organisations. A qualitative case-study design was therefore selected as most appropriate for in-depth, context-sensitive understanding.

1.10 Population, Sample and Sampling

The study's population includes key stakeholders in the South African chrome smelting industry. This includes production coordinators, engineering coordinators, operations superintendents, production managers, engineers, engineering managers, environmental specialists, and accountants working in both open- and closed-furnace operations. Their insights and experiences are crucial for identifying the operational, economic, regulatory, environmental, and technological issues the sector faces. These individuals should have at least 3 years of experience in the chrome smelting industry and be involved in decision-making that affects their operations. Individuals with less than 3 years of industry experience will be excluded from the population, as they may not have experienced sufficient seasonal challenges.

Due to the nature of this research, no specific number of participants has been defined. The aim was to collect data until saturation was achieved. The concept of data saturation comes from grounded theory, where data collection stops when new data no longer provide fresh insights, indicating that sufficient sampling has been reached (Charmaz, 2006).

A purposive sampling method was used. This enabled the researchers to use their judgment to select cases that would help them find an answer to the question and meet its objectives. This type of sample is commonly used in case study research to pick the most relevant instances with small sample sizes (Neuman, 2014). This enables the purposeful selection of participants with the most appropriate expertise and experience to deliver rich, insightful, and relevant data on the industry's challenges.

1.11 Recruitment Strategy

The population included in this research consists of operations superintendents, production managers, engineers, engineering managers, environmental specialists, and accountants working in both open- and closed-furnace operations. Approval from the gatekeeper was required to gain access to them. In this case, it is a senior manager, such as the general manager or works manager. Engineers and departmental administrators acted as mediators to facilitate participants' access. Once participants indicated their willingness to take part in the research, the researcher established contact to ensure they fully understood the study's purpose and their role. This approach ensured that the recruitment process adhered to ethical principles and respected participants' independence.

1.12 Informed Consent Process

The informed consent process was thorough and transparent. Participants were given an information sheet outlining the study's objectives, methodology, potential risks, and benefits. They were notified that they can withdraw from the research at any time without penalty. Participants were required to sign informed consent forms before engaging in the study. This form affirmed that participants' rights would be respected throughout data collection. Consent papers were collected before interviews began to ensure that participants fully understood the study and agreed to participate voluntarily (Creswell, 2018).

1.13 Data Collection

Key stakeholders were identified and recruited through professional networks. Names of participants were obtained from existing contacts with individuals working at a ferrochrome smelter. Initial contact was made via email, providing a brief overview of the study and an invitation to participate. Once participants agreed to take part, interviews were scheduled at times and locations convenient for them. Interviews could be conducted in person with participants living in the Rustenburg area and via Teams for those outside this area. Each interview was expected to last approximately 60-90 minutes. The interviews began with a brief introduction to the study's purpose and objectives, followed by questions designed to elicit detailed information on the challenges affecting the sustainability and growth potential of ferrochrome smelters. The semi-structured format allowed the interviewer to follow up on interesting points and explore emerging themes more deeply.

All interviews were audio-recorded or conducted via Teams with participants' consent to ensure accurate data collection. The recordings were carefully transcribed for later analysis. Transcripts were anonymised to protect participants' identities and stored securely in a password-protected database. The researcher also kept detailed field notes to supplement the interview data and provide additional context. In face-to-face interviews, the interviewer used MS Teams to record and transcribe the interview.

The data collection tool was a semi-structured interview guide with open-ended questions designed to explore the challenges facing South Africa's ferrochrome smelters. The guide included questions on economic, regulatory, environmental, and technological issues, along with prompts to encourage participants to elaborate on their experiences and perspectives.

1.14 Ethical Considerations During Data Collection

Participants' privacy was protected by obtaining informed consent before data collection, ensuring they understood the study's objectives, their rights, and how their data would be used (Creswell, 2014). Participants remain anonymous, and their identities are protected by pseudonyms or participant codes in all records and publications.

To maintain anonymity, all acquired data was anonymised, with any identifiable information deleted from transcripts and other documents. The data was securely stored in a password-protected database accessible only to the researcher.

1.15 Data Analysis

For this study, data were analysed using thematic analysis, a method that allows for the identification, analysis, and reporting of patterns within qualitative data. Thematic analysis is a method in qualitative research, and it offers a flexible and accessible approach to analysing complex data (Braun & Clarke, 2006:6). The identification of key themes and patterns emerging from the data provides an in-depth understanding of the challenges affecting the sustainability and growth potential of South Africa's ferrochrome smelters. Thematic analysis is ideal for exploring complex, multi-faceted issues such as the challenges facing ferrochrome smelters in South Africa.

The first step in the thematic analysis was open coding, in which the data were broken down into smaller units of meaning (codes) and categorised based on similarities and differences. Saunders, Lewis, and Thornhill (2009:509) refer to the grounded theory of Strauss and Corbin (2008), which holds that open coding is a process that allows researchers to remain open to new and emerging concepts during the initial stages of analysis. Creswell (2009:171) highlights the importance of iterative coding, in which the researcher continually revisits the data to refine and adjust codes. This process ensures that the codes accurately represent the data and that emerging themes are thoroughly explored.

According to Dawadi (2020:62), Braun and Clarke (2006) suggest that thematic analysis offers a high level of theoretical flexibility for identifying, describing, and interpreting patterns (themes) within a data set. This approach allows for a thorough examination of the data, providing detailed insights. This is an excellent fit for any qualitative study that aims to delve into intricate research topics. Braun and Clarke (2006) assert that adopting this approach enhances the validity of the analysis due to its ease of use, clarity, and adaptability.

Saunders, Lewis, and Thornhill (2009:66) emphasise the importance of thorough and transparent documentation throughout the coding process. In this study, all coding decisions were documented to provide a clear audit trail, enhancing the credibility of the findings. This documentation supported the dependability and confirmability of the research, as it also allows other researchers to follow the decision-making process and verify the results. Field notes must also be incorporated into the analysis, providing additional context and insights that enhance data interpretation. As Creswell (2009:164) notes, the inclusion of multiple data sources, such as interview transcripts and field notes, enhances triangulation, thereby contributing to the overall trustworthiness of the research.

The process followed these steps:

1. **Data Familiarisation:** Transcription and review of interview notes and relevant field notes.

2. **Initial Coding:** Open coding breaks data into smaller, meaningful segments.

3. **Search for Themes:** Group codes into broader themes, highlighting key issues affecting sustainability and growth potential in chrome smelting.

4. **Review of Themes:** Refine themes to ensure they accurately represent the data.

5. **Defining and Naming Themes:** Create final themes that encapsulate significant findings, such as economic constraints, technological barriers, or regulatory challenges.

6. **Reporting:** Synthesise findings, using illustrative quotes from participants to support the thematic categories. This approach provided a detailed understanding of the environmental, technological, and operational factors impacting South Africa's ferrochrome smelters (Braun & Clarke, 2006).

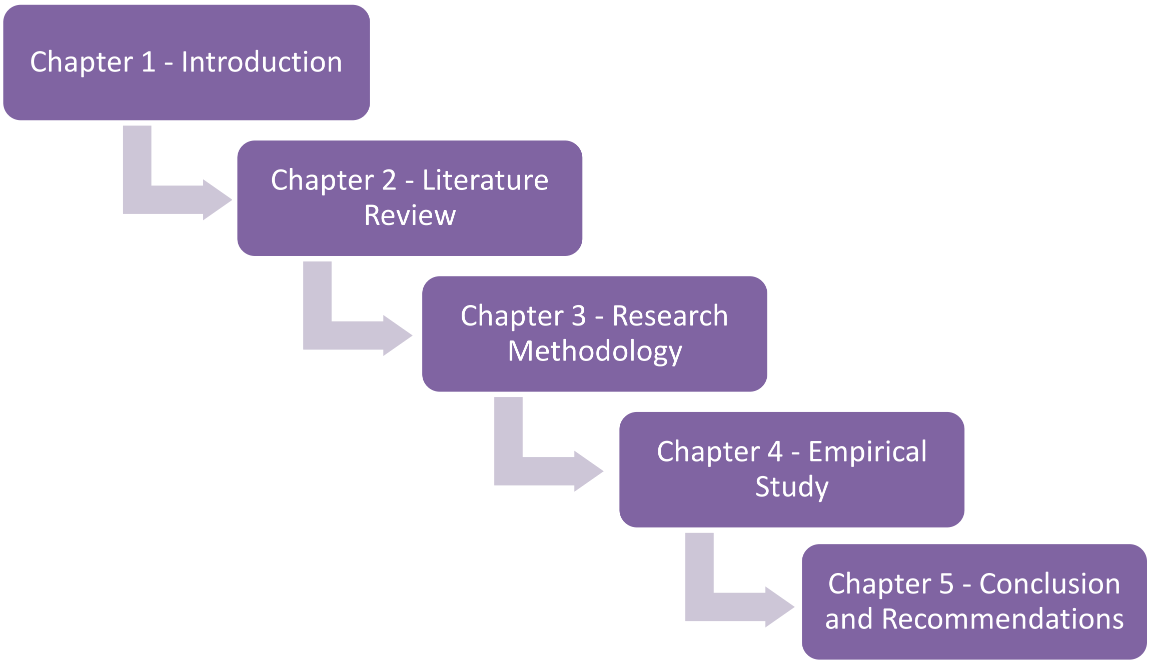
1.16 Ethical Considerations During Data Analysis

During data analysis, the researcher ensured that all data was handled with the utmost confidentiality and integrity. Any personal information that could potentially identify participants was kept anonymous. The analysis was conducted objectively, avoiding biases that could skew data interpretation. Additionally, the results were presented in a way that ensures no participant can be identified. Participants' privacy was protected by obtaining informed consent before data collection, ensuring they understood the study's objectives, their rights, and how their data would be used (Creswell, 2014).

To maintain anonymity, all acquired data were anonymised, with any identifiable information deleted from transcripts and other documents. The data was securely stored in a password-protected database accessible only to the study team. Furthermore, any tangible documents were scanned and saved in Google Drive, and the files are password-protected to prevent unauthorised access. The hard copies were destroyed. Participants remained anonymous, and their identities are protected by using fictitious names or participant codes in all records and publications.

1.17 LAYOUT OF STUDY

Figure 1: Layout of the study



- Chapter 1 - Introduction

This chapter introduces the study by emphasising the sustainability and growth challenges faced by South Africa's ferrochrome smelters. It offers a comprehensive overview of the research, outlining the context and significance of the topic. It highlights the issue being investigated and clarifies its importance. The chapter elaborates on the research problem, presenting a concise statement of the issue and explaining the necessity of the study.

- Chapter 2 – Literature Review

The literature review situates the study within current academic and industry research, identifies gaps, and establishes a theoretical framework. The discussion begins by addressing the economic, operational, regulatory, and environmental challenges previously emphasised in the literature. This analysis delves into global trends affecting the ferrochrome industry, highlighting China's market dominance, and investigates theoretical frameworks such as stakeholder theory and systems thinking to understand the complex interrelationships among these issues. A thorough examination of sustainability in industrial sectors and an analysis of case studies related to other resource-dependent industries are conducted. This chapter brings together essential themes and underscores the necessity of this research, emphasising the lack of qualitative investigation into stakeholders' experiences and perceptions within the South African context.

- Chapter 3 – Research Methodology

This chapter outlines the qualitative research design implemented to meet the research objectives. This research utilises a case study methodology, enabling a thorough investigation of the intricate issues in South Africa's chrome smelting sector. The participant group comprised of essential stakeholders, including operations superintendents, production managers, engineers, and accountants, chosen via purposive sampling. Semi-structured interviews are the primary method for collecting data, enabling participants to share their experiences and perspectives on economic, regulatory, environmental, and technological challenges. This chapter delves into ethical considerations, such as informed consent, confidentiality, and data security. Thematic analysis is employed for data analysis to uncover recurring patterns and themes, emphasising the importance of reliability and validity through triangulation and reflexivity.

- Chapter 4 – Empirical study

The empirical study presents results from interviews with stakeholders in the chrome smelting sector. The chapter begins by highlighting the main themes that emerged from the data, including elevated electricity costs, an unreliable energy supply, competition from China, and the challenges posed by environmental regulations. Stakeholder insights on operational inefficiencies and barriers to adopting new technologies are thoroughly examined. Direct quotations are used to strengthen the analysis and provide a detailed understanding of the topics. The findings are related to the research questions and objectives, demonstrating how they address gaps identified in the existing literature. The chapter wraps up by exploring the broader significance of the findings for the sector.

- Chapter 5 – Conclusion and recommendations

The final chapter summarises the key discoveries, emphasising their importance for the sustainability and progress of ferrochrome smelters in South Africa. It offers suggestions for addressing recognised challenges, including ways to reduce energy costs, improve regulatory compliance, and promote technological innovation. The chapter also discusses the study's limitations, including its focus on a single sector and its reliance on qualitative data. It suggests future research directions, like comparative studies with other industries. The research concludes by reflecting on its contributions to the field and the potential impact of its recommendations on policy and practice.

1.18 Conclusion

This chapter introduced the study by presenting the research context, motivating the research problem, and stating the research question, aim, and secondary objectives that guide the investigation. The chapter also clarified the scope of the study and outlined the structure of the dissertation to support a coherent research process. Having established the foundational framing of the research, Chapter 2 now critically reviews the relevant academic and industry literature, synthesises what is known about sustainability and growth challenges in ferrochrome smelting, and identifies the gaps that the empirical component of this study addresses.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

This chapter critically reviews the evidence on the sustainability challenges facing South Africa's ferrochrome smelters. The review is organised thematically and covers the following aspects which are industry structure and context, economic and market challenges, electricity pricing and supply constraints, policy and regulatory developments, environmental and social pressures, logistics bottlenecks, technology and operational pathways (energy efficiency, waste valorisation, renewables integration) and emerging climate trade risks, notably the EU's Carbon Border Adjustment Mechanism (CBAM). The chapter concludes with a synthesis and identifies research gaps to guide with further empirical work (DTIC, 2020; Dlamini & von Blottnitz, 2023; Creamer, 2025).

2.2 Conceptual framework for the study

This study is framed conceptually as an interconnected system of constraints affecting sustainability and growth in South Africa’s ferrochrome smelting industry. The literature indicates that cost competitiveness and continuity of operations are shaped by interacting forces, including electricity pricing and reliability, logistics performance, market dynamics (including China’s role), regulatory and environmental pressures, and firm-level technology and investment decisions (DTIC, 2020; Dlamini & von Blottnitz, 2023).

Within this systems-oriented framing, the study also adopts a stakeholder lens to interpret how government, regulators, labour, communities, and industry bodies influence operational risk, compliance burdens, and strategic choices. This supports the study’s focus on stakeholder experiences and perceptions and provides a structured way to interpret the empirical themes in Chapter 4 in relation to the literature. Accordingly, the literature review is organised thematically to build this conceptual framing and to identify the gaps that motivate the qualitative inquiry.

2.3 Overview Of South Africa's Chrome Smelting Industry

South Africa possesses most of the world's viable chromite resources situated in the Bushveld Igneous Complex and has been a leader in the production of ferrochrome. However, its domestic market share has diminished over the years as cost of production has increased and lower-cost competitors have expanded capacity (DTIC, 2020; Beukes, van Zyl & Ras, 2012). The ferrochrome sector comprises of both integrated mining–smelting groups and non-integrated producers. A notable development since the mid-2000s is industrial symbiosis with the PGM sector, in which UG2 tailings are processed to recover chromite, reducing smelter ore consumption and encouraging cleaner production practices (UCT Thesis, 2020).

South Africa's position in the chromite value chain is underpinned by a huge resource base. Southern Africa hosts the majority of the world's chromite reserves. It alone makes up more than half of the world's chromite production. This is due to several billion tonnes of combined reserves and resources identified in the Bushveld Complex (Jones, 2024). Over the past two decades, an increasing amount of chromite has been recovered as a by-product from the UG2 PGM operations, which has further strengthened the supply of raw materials for ferrochrome producers and reinforced the strategic importance that South African ore has in global supply chains (Jones, 2024).

Operational headwinds have intensified. In the beginning of 2025, Glencore–Merafe Chrome Venture ceased smelting operations at their Boshoek plant from 1 May and at Wonderkop plant from 31 May. It also temporarily suspended operations at its Lion smelter to carry out scheduled maintenance and rebuilds. The entity had cited structural issues that threaten long-term sustainability as the reasons for suspending operations (Glencore SA, 2025; Parker, 2025). From public commentary and companies' financial disclosures, both have revealed that South Africa's local producers of ferrochrome are more frequently switching between smelting operations and exporting the ore when domestic beneficiation delivered financial margins that are below the breakeven point (Miningmx, 2025; Creamer, 2025).

2.4 Worldwide Ferro-Chrome Installed Smelting Capacity Versus Utilised Capacity.

2.4.1 South Africa

South Africa has historically hosted a large FeCr fleet. However, ongoing increases in electricity costs and supply disruptions have led to curtailments. In 2025, the Glencore Merafe Chrome Venture halted smelting operations at Boshoek on 1 May 2025 and at Wonderkop on 31 May 2025 while keeping Lion operational for limited production and maintenance periods (Glencore, 2025; Merafe, 2025). These measures continue a multi-year pattern of intermittent mothballing across the sector, despite the country's rich ore endowment (Merafe, 2025; Merafe, 2024).

2.4.2 Installed smelting capacity, production and utilisation

South Africa's ferrochrome industry has become one of the largest in the world, supported by substantial installed smelting capacity. As early as 2007, Basson, Curr and Gericke (2007:7) noted that "by early 2007 the gross installed annual ChCr capacity (including feedstock to refined products and reclaimed alloy from slag dumps) would be in the order of 4.2 million tonnes." This figure set the benchmark for the country's ferrochrome smelting scale. However, he warned that expansion projects were limited by Eskom's constrained power supply and rising electricity costs. More recently, Dlamini and von Blottnitz (2022:6) reported that "total South African capacity was 4174–4895 kt FeCr/year," indicating a relatively stable but mature capacity profile. Collectively, these findings show that South Africa's installed ferrochrome capacity has consistently remained within the 4.2-4.9 million tonnes per year range, underscoring its longstanding dominance in the global ferrochrome market. Figure 2 below shows the ferrochrome production companies that existed from 2006 and those that remain in 2020, along with their production throughput capacities.

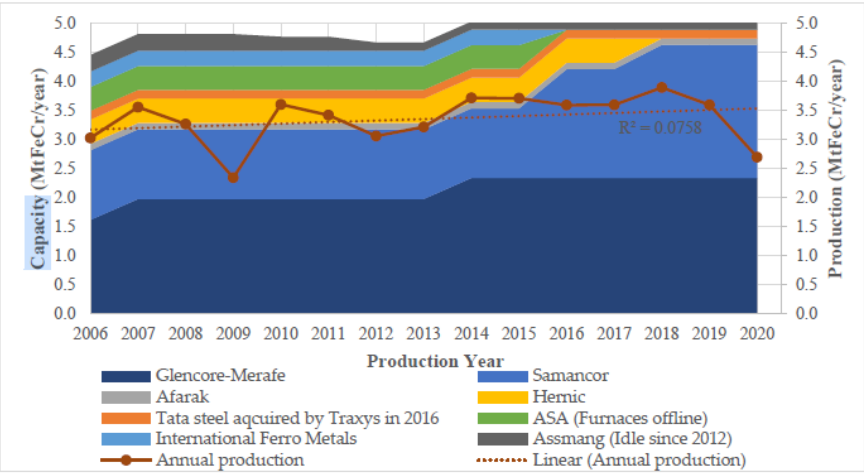


Figure 1. Ferrochrome production of South African companies between 2006 and 2020 [27–34].

Figure 2 Ferrochrome production of South African companies between 2006 and 2020.

(Dlamini & von Blottnitz, 2023:6)

According to Merafe (2024), approximately 3.3Mt of the world's 17.5Mt of ferrochrome was produced and supplied by South Africa in 2024. Despite the substantial installed smelting capacity, actual production and utilisation of these facilities have declined significantly in recent years, mainly due to rising electricity costs, unreliable supply, and ageing infrastructure.

The Minerals Council South Africa (2023) reports that this industry's effective utilisation rates have averaged between 70% and 80%, but this has worsened as load curtailments and tariff hikes increased. According to Miningmx (2025), none of Glencore's 22 furnaces were operational in September 2025. It further stated that only three of Samancor's 24 facilities remained active, illustrating an unprecedented contraction of South Africa's ferrochrome smelting sector. This article attributed these widespread shutdowns to the soaring electricity tariffs, which are now roughly 50% higher than in China and account for up to 60% of total production costs, compounded by Eskom's unreliable supply and infrastructure failures (Miningmx, 2025). These closures have resulted in over 2,000 job losses and placed an additional 2,500 positions at risk, highlighting the severity of the crisis facing the domestic ferrochrome industry. Combined, these findings highlight the paradox of a country possessing one of the largest global installed ferrochrome capacities (≈5 Mt FeCr/year) but operating far below potential due to structural energy constraints and escalating input costs.

About 90% of ferrochrome produced is used in stainless steel and specialised steel production. Stainless steel production in China reached 40.7 MT in 2024. Information available regarding ferrochrome production from past data shows that South Africa was still the world's largest ferrochrome (FeCr) producer in 2006, producing roughly 3.0 Mt per year, and ahead of China (Jones, 2024). As electricity constraints, tariff escalation, and supply instability intensified, domestic smelting growth stalled. China has continuously expanded its ferrochrome (FeCr) smelting capacity and imports chrome ore mainly from South Africa. By 2012, China had overtaken South Africa as the leading ferrochrome producer, illustrating how power shortages led to cost disadvantages that resulted in a loss of global market share despite South Africa's substantial installed smelting capacity (Jones, 2024).

2.4.3 Furnace technologies in South Africa

2.4.3.1 Overview of Furnace Types

South Africa's ferrochrome industry operates a variety of furnace technologies that reflect different stages of technological maturity, feed flexibility and energy efficiency. According to Basson, Curr and Gericke (2006:4), four main process routes are established:

1. Conventional semi-closed submerged-arc furnaces (SAFs) are the oldest technology and still widely used. These furnaces smelt coarse and fine chromite ores and sometimes without prior agglomeration. They typically operate on an acid slag (basicity factor < 1) and are valued for their low capital costs and raw material flexibility (Basson et al., 2006:5).
2. Closed SAFs with oxidative-sintered pellets (Outokumpu process) – a more modern setup combining pelletising and sintering with closed-furnace operation and off-gas energy recovery. This configuration enhances chromium recovery and electrical efficiency compared with conventional SAFs (Beukes, Dawson & van Zyl, 2010:744).
3. Closed SAFs with hot-charged, pre-reduced pellets (Premus process family) – the most energy-efficient commercial route in South Africa. Pellets are pre-reduced in rotary kilns and charged hot into the furnace, operating on a basic slag (basicity > 1). Xstrata

developed and patented this Premus process at Lydenburg between 1998 and 2001 (Naiker, 2007:113).

4. Direct-current (DC) arc furnaces are single-electrode furnaces that smelt 100% chromite fines without the use of metallurgical coke. They provide higher chromium recoveries than AC submerged-arc units and are particularly suitable for ore-fines feedstocks (Sager et al., 2010:803–805.

2.4.3.2 Industrial Adoption and Capacities

Basson et al. (2006:5) list the installed capacities of major South African ferro-alloy plants. The following examples illustrate the scale and diversity of furnace technologies:

- Xstrata/Glencore Alloys operates multiple technologies:
    - Lion (Steelpoort) – two × 60 MVA closed AC Premus furnaces producing about 340 000 t charge-chrome (ChCr) per year (Basson et al., 2006:6).
    - Lydenburg – three × 33 MVA closed AC Premus furnaces (~380 000 t ChCr p.a.) (Naiker & Riley, 2006:301).
    - Rustenburg – five × 33 MVA semi-open AC furnaces (~410 000 t p.a.) employing conventional and recovery processes (Naiker & Riley, 2006:298).
    - Wonderkop – six × 45 MVA semi-open AC units (~460 000 t p.a.) with low-temperature (700 °C) pelletising (Naiker & Riley, 2006:299).
    - Boshoek – two × 60 MVA closed AC Outokumpu-type furnaces (~240 000 t p.a.) (Naiker & Riley, 2006:300).

- Samancor Chrome employs both semi-closed and closed SAFs across its Ferrometals, Middelburg Ferrochrome and Tubatse Ferrochrome plants, with a combined annual output of roughly 1 million t ChCr (Visser, 2006:285).

- Middelburg Ferrochrome (Samancor) also operates DC-arc furnaces of 44 MW and 60 MW, smelting Transvaal chromite fines with higher chromium recovery and without coke (Sager et al., 2010:803).

Collectively, Basson et al. (2006:6) estimate South Africa's installed ferrochrome capacity at over 4 million t per annum, confirming the country's global dominance.

2.4.3.3 Comparative Efficiency and Performance

The relative efficiency of each technology is influenced mainly by electricity consumption, feed utilisation and chromium recovery:

- Premus pre-reduction route – reduces electrical energy demand by about a third compared with conventional SAFs, increases furnace throughput by up to 54 %, and produces approximately one-third less slag (Naiker, 2006:112). Oxygen enrichment in the kiln enhanced total kiln energy output by around 31 % (Naiker, 2006:113).
- Outokumpu sinter-and-closed-furnace systems – achieve reduced specific energy consumption and improved chromium recoveries through agglomeration and off-gas preheating (Beukes et al., 2010:744).
- DC-arc furnaces enables the smelting of 100% fines and achieve higher metal recovery; their electrical design provides stable operation and reduces harmonic distortion to the grid (Sager et al., 2010:804–805).
- Conventional semi-closed SAFs offer feed flexibility but have the lowest energy efficiency and higher emissions compared to modern pelletising or pre-reduction technologies (Basson et al., 2006:5; Beukes et al., 2010:744).

2.4.3.4 Sustainability Implications

From a sustainability perspective, technologies that reduce energy intensity and utilise ore fines efficiently directly support South Africa's decarbonisation and resource-efficiency goals. The Premus and DC-arc technology routes, which reduce electrical consumption and enable the utilisation of fines, represent the most sustainable pathways for the country's ferrochrome producers (Naiker, 2006:111; Sager et al., 2010:803).

Recent assessments argue that future chromite smelting routes will be selected on both environmental and economic criteria, and that open or semi-closed SAFs are unlikely to remain viable in the long term due to lower chromium recoveries, higher specific energy consumption, and challenges in controlling hexavalent chromium and other emissions (Jones, 2024). To compare, the DC arc furnaces and closed SAFs with sintered or pelletised feed are identified as the preferred technologies because they combine better energy performance, higher recoveries and reduced environmental risk, aligning with South Africa’s existing Premus and DC-arc installations and providing a more sustainable basis for future investment (Jones, 2024)

2.4.4 China

2.4.4.1 Smelter additions and policy direction

China has rapidly expanded its ferrochrome smelting capacity over the last decade and now leads global smelting output. Despite having limited domestic ore, they managed to achieve this by importing ~17 Mt of chrome ore from South Africa in 2024 (Merafe, 2024). Their Environmental or energy policy in Inner Mongolia and other hubs has driven the closure of open and semi-closed furnaces below 25 MVA and transition to closed-type SAFs (Gaini, 2021; DHHI, 2023).

2.4.5 Capacity, production and utilisation

The installed FeCr capacity is approximately 6.0–6.5 Mt/y. This is according to MarketGrowthReports (2025) and ICDA (2025). Industry sources estimate that 2024 production reached about 3.7 Mt, with short-term fluctuations observed in monthly Mysteel surveys (Mysteel, 2023; MarketGrowthReports, 2025). Their furnaces are mainly closed SAFs, typically with modules of 25–36 MVA, and large multi-furnace parks such as 6 × 30 MVA are referenced in equipment EPC literature (DHHI, 2023; IOM3, 2021).

2.4.6 Other major ferrochrome producers (capacity and technologies)

Note on interpretation: "Capacity" below refers to annual installed FeCr capacity where available from public sources; where only production is available, we cite production as a proxy and indicate the limitation.

2.4.6.1 Kazakhstan

Kazakhstan's FeCr production is generally reported to be around 1.4 million tons per year (MarketGrowthReports, 2025). Kazchrome (ERG) produced 1.85 million tons of ferroalloys in 2024, which was mostly comprised of ferrochrome at their plants in Aksu and Aktobe. Plant-level data has shown that Aksu manage to exceed 1.0 million tons per year and Aktobe exceeds 0.7 million tons per year, which is consistent with the country's focus on FeCr (Kazchrome, 2025). The use of large, hermetically sealed DC arc furnaces, ranging from 72 to 81 MVA, alongside modern closed Submerged Arc Furnaces (SAFs), is common. The adoption of DC technology seeks to improve energy efficiency and recover off-gas (Kazchrome, 2025; DHM Group, 2025).

2.4.6.2 India

India has usually produced around 1.0–1.2 million tonnes of FeCr per year (ICDA, 2025). The country's ongoing expansions include FACOR's project, which will add 300,000 tonnes annually. It features 2 × 75 MVA closed SAFs and steel belt sintering. This project is expected to commence operation in the middle of this decade (Metso, 2024; GeoResources, 2024). Most furnaces are closed SAFs up to 75 MVA, while DC open arc technology is also used for fines (IspatGuru, 2018; Metso, 2024).

2.4.6.3 Turkey

Turkey's output has been surveyed at 161,500 tonnes per year of FeCr (both LC & HC) and an additional 7,300 tonnes of FeSiCr during 1990–2006. Since then, upgrades have been made at plants like Eti Krom. Furnaces include a mix of open and closed SAFs; legacy open units of 17 MVA and closed units of 30 MVA are documented. In modern operations, closed or semi-closed furnaces are generally favoured for better energy efficiency and emissions control (Aydin et al., 2007; ICDA, 2025)

2.4.6.4 Zimbabwe

Around 2008, approximately 490,000 tonnes per year were produced in Zimbabwe, mainly at ZIMASCO and ZimAlloys plants. At present, there are initiatives to resume production, targeting a throughput of around 120,000 tonnes annually at ZimAlloys after a ten-year break, signalling a planned slow recovery to earlier levels (SAIMM, 2008; EquityAxis, 2024). Furnaces are primarily semi-closed SAFs, typically 7.8–12 MVA at Maranatha, with plans to add or upgrade DC arc furnaces (Maranatha, 2025; SAIMM, 2008).

2.4.6.5 Oman

Oman has become a regional ferrrochrome supplier to the Asian markets. They have modern closed SAF in operation with a capacity generally estimated at around 0.2–0.3 Mt/y, though detailed plant-specific data are less publicly available (ICDA, 2025; PMarketResearch, 2025). Their furnaces are closed-type SAFs, representing a newer generation focused on energy efficiency and reduced emissions (ICDA, 2025; PMarketResearch, 2025).

2.5 Economic and market challenges

2.5.1 Global competition and price pressures

The global supply and demand balance and the global stainless steel cycles have the biggest effect on ferrochrome market prices. Low-cost ferrochrome producers in China, India, and Kazakhstan have made it harder for South African smelters to compete, especially older plants that use a lot of energy. This has led to a long-term loss of global market share (DTIC, 2020; Mining Weekly, 2021). Some South African producers put chrome ore sales ahead of domestic beneficiation to save money when prices are low or weak, especially when electricity costs and curtailments make smelting too expensive (Miningmx, 2025; Creamer, 2025).

The growth of low-cost global ferrochrome production shows how closely South Africa's electricity situation is linked to China's rise in ferrochrome production. Most of South Africa's chromite was turned into ferrochrome locally until the middle of the 2000s. This was possible because electricity was cheap and there were plenty of generation reserves (Jones, 2024). After 2008, when power shortages and rapid tariff increases began, South Africa's smelters' throughput became more and more limited. This made producers send raw chromite ore to China whenever the margins for converting it into ferrochrome fell below zero (Jones, 2024). The rise in chrome ore exports has caused ore prices to go up and ferrochrome market prices to go down. This change in trade patterns allowed China to speed up the growth of FeCr capacity by using South African ore, which eventually made China the world's largest ferrochrome producer (Jones, 2024).

2.5.2 Global Supply Chain, Exporters/Importers, and Market Entries

The global chromium supply chain is very centralized, with most chromite ore resources found in Southern Africa and Kazakhstan. This gives these areas a lot of power over the stability of the global supply (USGS, 2025). In 2023, South Africa was still the largest exporter, sending about 17.8 million tons of chromite ore worth about US$3.94 billion. Turkey, Pakistan, and Kazakhstan are also big exporters (World Bank, 2023). Their main markets are China, which is the world's biggest producer of stainless steel and the biggest user of ferrochrome (World Stainless, 2025). Kazakhstan, China, Turkey, and India are the main countries that export low- and medium-carbon ferrochrome (LC/MC FeCr) (World Bank, 2023). Because of this, the supply chain has a few resource-rich hubs that only supply a few major consuming areas. New smelting sites like Indonesia and Zimbabwe are becoming more competitive (SEAISI, 2024; Mining Zimbabwe, 2025).

2.5.3 Market Price and Demand Influencers

The main reason for the demand for ferrochrome is the production of stainless steel. About 90% of the ferrochrome made is used to make stainless and specialised steel (World Stainless, 2025). In 2024, the world's stainless-steel melt-shop output rose by about 7% from the previous year to 62.6 million tonnes. This was mostly because China continued to be the world's largest producer (Merafe, 2024). However, regional demand is very different and is affected by things like trade tensions, macroeconomic factors, and downstream consumption patterns (USGS, 2025). In the middle of 2024, the long-standing European quarterly benchmark for ferrochrome was removed. This made spot pricing and weekly assessments more important (Fastmarkets, 2024). This change has made prices more volatile and caused prices to diverge between regions. For example, European and Chinese spot prices often go in opposite directions because of local demand and cost conditions (Fastmarkets, 2025). Energy tariffs are a major cost driver. For example, they went up by about 12.74–13.29% for large industrial users in South Africa between 2024 and 2025 (Eskom, 2024). Environmental rules also affect costs. For example, the European

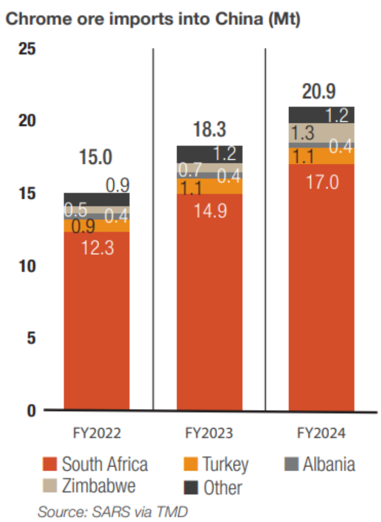
Union's Carbon Border Adjustment Mechanism (CBAM) will be fully in place by 2026, and South Africa's Carbon Tax went up to R190/tCO_2e in 2024. These actions are likely to have an effect on landed costs and the ability to compete globally (European Commission, 2025; Anthesis, 2024).

2.5.4 New Market Entrants Globally

There have been big changes in the ferrochrome market, especially in Asia and Africa, where new companies have entered the market. Indonesia has set up integrated stainless steel production centers, like the Tsingshan–Jindal joint venture in Morowali, which includes local ferronickel and ferrochrome facilities. This means that Indonesia doesn't have to rely as much on imports (SEAISI, 2024). Zimbabwe has also increased its ferrochrome smelting capacity by using ore resources and logistics networks that connect with South Africa (Mining Zimbabwe, 2025). This was made possible by investments from Afrochine and Zimasco. These changes make it harder for South African smelters to compete because their energy and logistics costs are higher than those of their integrated counterparts in Asia (SEAI, 2024).

2.5.5 Use of Ferrochrome and Demand Trends

Ferrochrome is mostly used to make stainless steel, so the amount of stainless steel made around the world has a big effect on the demand for ferrochrome. In 2024, the production of stainless steel around the world went from 60.4 Mt in 2023 to 63.3 Mt, with China making the biggest contribution (World Stainless, 2025). This growth shows how closely the stainless steel and ferrochrome markets are connected, as depicted in Figures 3 and 4 below.



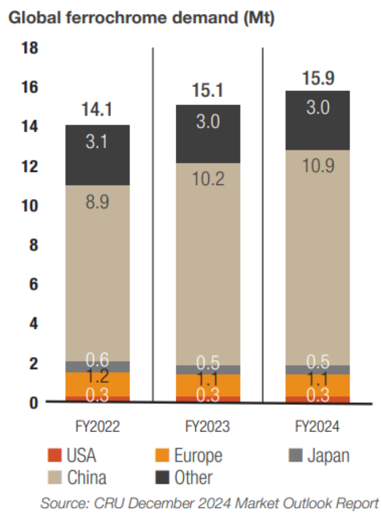


Figure 3: Global ferrochrome demand and Chrome imports into China (Merafe Resources Limited, 2024)

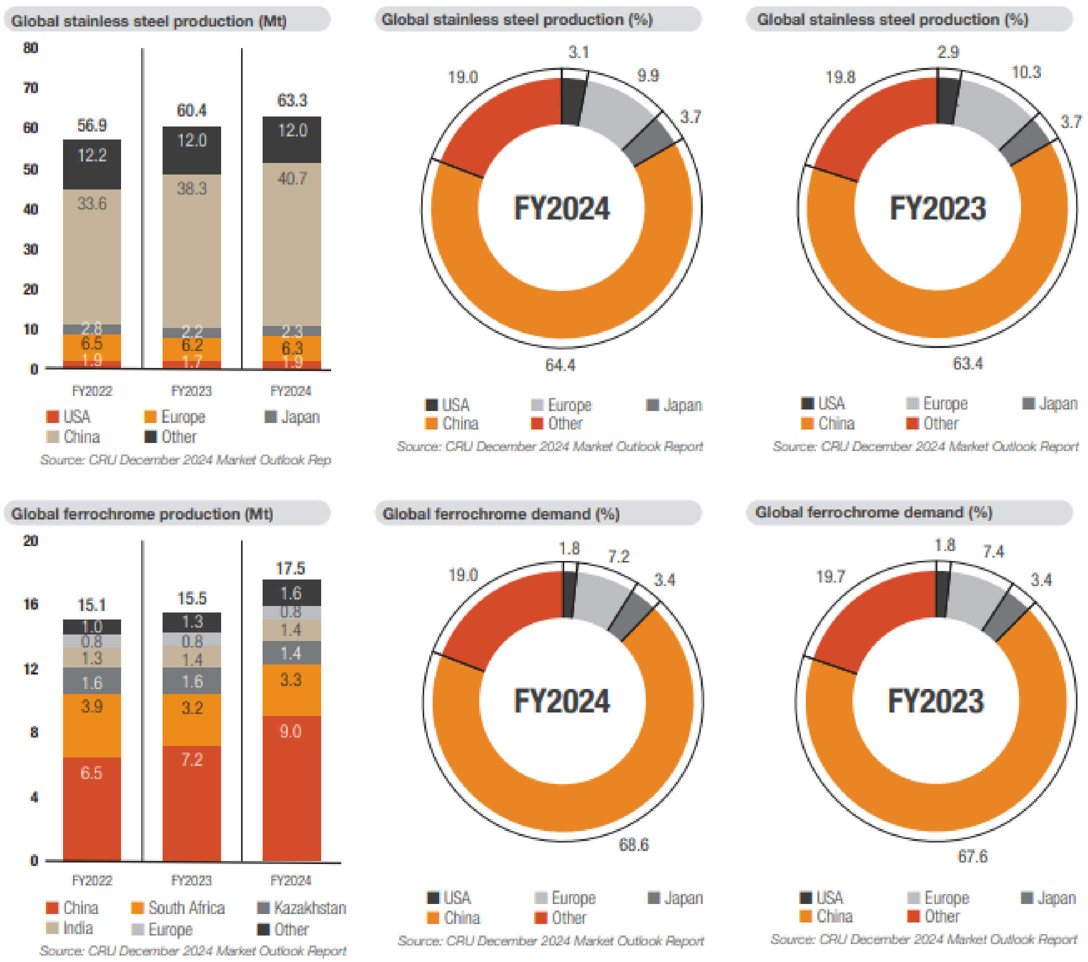


Figure 4: Key market indicators (Merafe Resources Limited, 2024)

Figures 3 and 4 above show how much stainless steel is made in different parts of the world and how much ferrochrome South Africa exports can help us understand how demand is changing. This illustrates how much China relies on South Africa for chrome ore to produce ferrochrome, and how the ferrochrome and stainless steel industries continue to grow globally (Merafe, 2024; OEC, 2025).

2.5.6 Trend and Determinants of Ferrochrome Prices

Ferrochrome prices have experienced considerable volatility since the discontinuation of the European quarterly benchmark in mid-2024, with markets now depending on weekly spot assessments (Fastmarkets, 2024). Regional price variations have become more evident, with European prices are low because demand is low, while Chinese prices go up and down because of too much supply and tender activity (Fastmarkets, 2025).

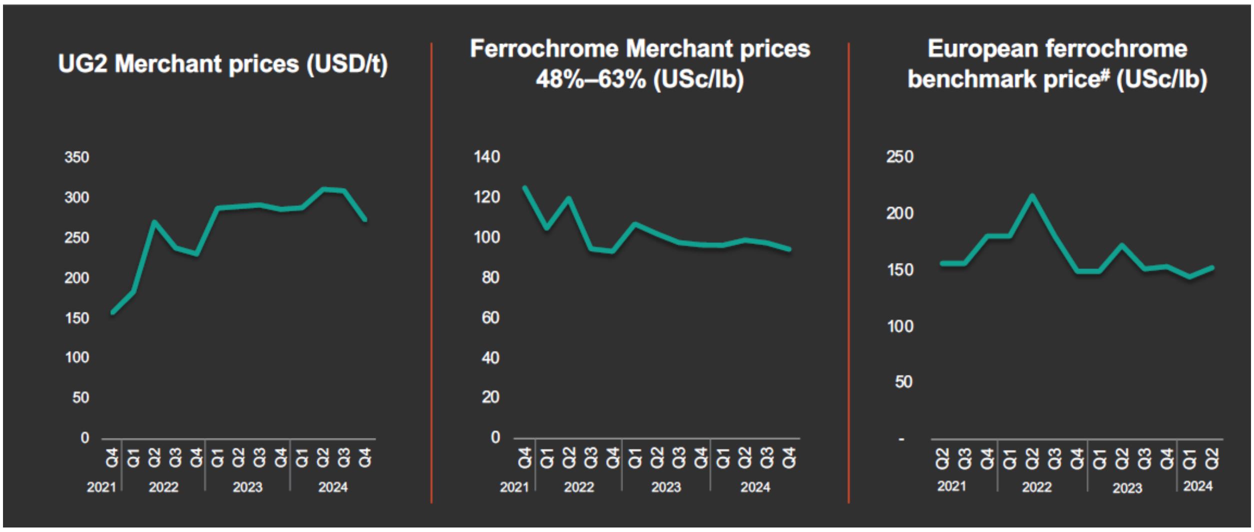


Figure 5: Chrome ore and ferrochrome prices (Merafe Resources Limited, 2024)

Figure 5 indicates how prices are still below their previous highs, even though stainless steel production has gone up. This shows how structural and policy factors affect how the market works (USGS, 2025). Also, the price of ferrochrome is affected by a number of factors that are all connected. The main reason for demand is still the production of stainless steel, but the cost of raw materials, especially chrome ore, has a big impact on the economics of smelting (World Stainless, 2025; USGS, 2025).

In South Africa, where electricity prices are going up quickly, Eskom's electricity prices and reliability are still major concerns (Eskom, 2024). Logistics performance, such as how well rail and ports work, also affects how competitive exports are (Transnet, 2025). Also, environmental rules like CBAM and South Africa's Carbon Tax will probably raise compliance costs and change how companies source goods around the world (European Commission, 2025; Anthesis, 2024). The switch to spot pricing has made it even clearer how important short-term market conditions are for setting prices (Fastmarkets, 2024).

2.5.7 High Stock Levels of Ferrochrome in South Africa in 2025

High levels of ferrochrome inventories in South Africa during 2025 can be attributed to several factors. First, the switch to spot pricing and the end of the benchmark system lengthened procurement timelines, European demand dropped, and offtake slowed (Fastmarkets, 2024). Second, export volumes fell in the middle of 2025. Shipments in June fell to about 19.5% from the month before. This was a sign of buyer caution and problems with shipping (OEC, 2025). Third, the government's approval of chrome ore export controls and electricity incentives in June 2025 may have made buyers hesitant to buy (Engineering News, 2025). Lastly, even though some rail infrastructure improvements were made, logistical problems continued to make it hard to move materials (Transnet, 2025). In general, these factors keep stock levels high even as stainless steel production is rising (World Stainless, 2025).

2.6 Electricity Tariffs, Load Curtailment and Cost Structure

2.6.1 Cost Pressure from Tariffs and Load Curtailment

Electricity is the primary controllable cost in chrome production. In March 2025, NERSA decided that Eskom could raise its tariffs for direct customers by an average of 12.74% for FY2025/26. This put even more pressure on smelters that use a lot of energy (NERSA, 2025; Eskom, 2025). Persistent load shedding and curtailment make furnaces less stable and less useful, use more energy, and can lower metal recoveries, which makes them less competitive (Mining Weekly, 2021; Dlamini & von Blottnitz, 2023).

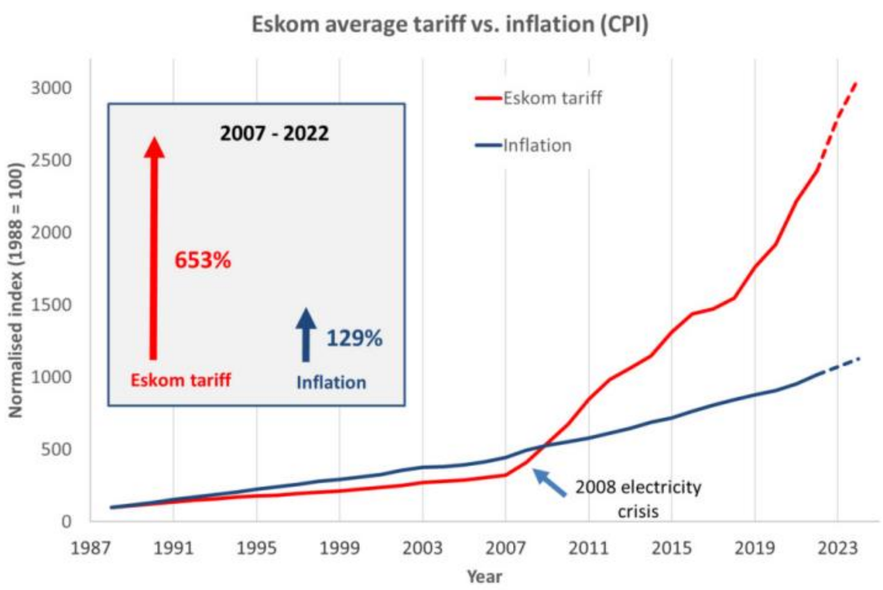


Figure 6: Eskom's tariff increased much more rapidly than inflation

Figure 6 illustrates how Eskom's tariffs increased from the late 80's compared to the country's inflation rate. For many years in the past, Eskom was among the cheapest electricity suppliers in the world, however this began to change due to tariff hikes outpacing the country's inflation from 2007. South African smelters had very low real electricity prices and a large generation reserve margin. This led to rapid growth in ferro-alloy capacity and the construction of several FeCr smelters (Jones, 2024). Since the electricity crisis in 2008, however, tariffs have gone up much faster than inflation, and the power system has been marked by lower reserve margins, load shedding, and curtailment. This has taken away the historical cost advantage that used to make South Africa the leader in global ferrochrome production (Jones, 2024).

2.6.2 Policy Interventions: Negotiated Pricing Agreements (NPAs)

South Africa has reaffirmed that Negotiated Pricing Agreements (NPAs) will remain available to ensure that strategic, energy-intensive assets remain operational. In July 2025, the Cabinet authorised the Department of Electricity and Energy to finalise an electricity tariff realignment (NPA style) for ferrochrome, along with other measures (Creamer, 2025; National Coal, 2025). The lessons learned from the Hillside aluminium NPA emphasise a macro trade-offs: Meridian Economics estimates an effective discount approximatey 50% worth around R10 billion per year in FY2025/26; for such a concession to be net beneficial, the economy-wide gains must surpass the net discount, highlighting the importance of transparent cost–benefit assessments for any ferrochrome NPAs (Meridian Economics, 2025; MyBroadband, 2025).

2.6.3 Eskom's Capacity and Reliability Constraints

Eskom's power stations are mainly coal-fired, which constitutes most of its installed capacity. In 2024, Eskom's total capacity was reported to be around 55,423 MW, with coal power stations supplying 40,544 MW. Renewables such as solar, wind, and concentrated Solar Power contributed 6,281 MW, while diesel and gas turbines accounted for 3,414 MW. Pumped storage added 2,724 MW, nuclear 1,860 MW, and hydro 600 MW (CSIR, 2025). However, the actual available capacity was significantly lower due to planned and unplanned outages. In June 2025, Eskom reported about 30,703 MW of available generation capacity, which comfortably met the winter peak demand of 28,810 MW (OurPower, 2025). The gap between installed and available capacity highlights ongoing maintenance issues and the ageing coal fleet. These reliability problems add to the impact of high tariffs, as unstable supply increases smelting costs.

2.6.4 Electricity Intensity of Ferrochrome Smelting

Ferrochrome production is energy-intensive and requires substantial energy. The Submerged Arc Furnaces (SAFs), mainly used in South Africa, typically use between 2.4 and 4.8 MWh per tonne, depending on the furnace design and process conditions (Semantics Scholar, 2023). The Advanced closed SAFs with pre-heating or prereduction can use as little as 2.8 MWh/tonne of energy, while traditional open SAFs may need as much as 4.0 MWh/tonne (Metso Outotec, 2023; Pmarketresearch, 2023). Direct Current Arc Furnaces (DCAFs) and hybrid options are more efficient, but they need a lot of money up front (Wei et al., 2023).

2.6.5 International Benchmark: China's Energy System and Tariffs

China's energy sector serves as a useful benchmark to compare energy cost competitiveness. By the middle of 2025, China's total installed generation capacity had expanded to more than 3.6

TW. More than 56% of that capacity came from non-fossil sources; however, coal still accounted for most of the actual generation (EIA, 2025; PV Magazine, 2025). In early 2025, solar and wind power together produced more electricity than coal for the first time. This shows how quickly China is using renewable energy (Climate Energy Finance, 2025). This varied energy mix helps keep industrial tariffs stable and makes Chinese ferrochrome and stainless steel producers more competitive.

2.6.6 Comparative Cost Analysis: South Africa vs China

Electricity costs are a big part of what makes ferrochrome smelters competitive. Energy costs make up about 40–50% of total production costs (FAPA, 2025). When one compare South Africa and China, it can be observed that the cost of electricity for industry is very different. This has a direct effect on the long-term viability of South African ferrochrome smelters.

2.6.6.1 South Africa

South Africa's electricity tariffs for large industrial users have risen substantially over the past decade. For the 2024/25 financial year, the National Energy Regulator of South Africa (NERSA) approved an average increase of 12.74%, resulting in tariffs for Eskom's Megaflex and Nightsave customers ranging from R2.90 to R3.50 per kWh during off-peak periods and up to R4.50–R5.00 per kWh during peak times (Eskom, 2025; NERSA, 2025). At an exchange rate of about R19/USD, this equates to US$0.17–0.25 per kWh, making South African electricity some of the most expensive for energy-intensive industries worldwide (Durban Municipality, 2025). These high tariffs are compounded by additional costs, such as carbon taxes and reliability issues, which further reduce smelters' competitiveness (Anthesis, 2024).

2.6.6.2 China

China still maintains relatively low and stable industrial electricity tariffs, supported by a diverse generation mix and government-driven energy policies. As of 2025, the average industrial tariff for high-voltage users (35 kV and above) was approximately 0.63 RMB per kWh, equivalent to US$0.088 per kWh (CEIC, 2025). Most provinces report tariffs of US$0.08–0.09 per kWh, which is less than half the cost faced by South African smelters (China Briefing, 2025). This cost advantage is further enhanced by China's rapid deployment of renewable energy, which has stabilised electricity prices and reduced reliance on imported fuels (Climate Energy Finance, 2025).

2.6.7 Direct Comparison and Implications

The cost gap between the two countries is evident: South African smelters pay two to three times more for electricity than their Chinese counterparts. This structural imbalance substantially affects production economics, as electricity is the most significant single cost element in ferrochrome smelting. As a result, Chinese producers enjoy lower operating costs and more flexible pricing in global markets, while South African smelters experience margin squeeze and, in some cases, operational cuts (FAPA, 2025; Energise, 2025).

In 2025, commercial electricity tariffs in South Africa are significantly higher than in China. According to Eskom's official tariff booklet, South African commercial electricity rates range from USD 0.17 to 0.25 per kWh, depending on customer categories and usage profiles (Eskom, 2025). These rates include energy charges, network access, and service fees. They are affected by an 11.32% tariff increase approved by the National Energy Regulator of South Africa (NERSA) for the 2025/2026 financial year. Conversely, China's average business electricity price as of March 2025 is reported at CNY 0.794 per kWh, roughly equivalent to USD 0.112 per kWh, covering generation, transmission, distribution, and taxes (GlobalPetrolPrices.com, 2025). This gap indicates that South African commercial electricity tariffs are approximately 1.5 to 2.2 times higher than those in China, which could influence industrial competitiveness and investment decisions in both economies.

2.6.8 Impact of Raw Material Composition on Energy Use

The energy required for smelting largely depends on the Cr/Fe ratio of the chromite ore, the slag basicity, and the quality of the reductant. High-grade ores with higher Cr/Fe ratios and optimal slag chemistry lower energy use, while low-grade ores and poor reductant quality raise the specific energy demand (IJERT, 2016). Pre-reduction of ore and feed pre-heating can reduce energy consumption by 0.7–0.8 MWh/t, enhancing furnace efficiency and lowering greenhouse gas emissions. Process models show that upgrading from conventional SAF to closed SAF with preheating can decrease emissions by 23%, and using hydroelectricity could cut emissions by up to 68% (Wei et al., 2023).

2.7 Production Inputs & Technology

2.7.1 Process overview and energy intensity

Ferrochrome is produced by reducing chromite ($FeCr_2O_4$) with carbonaceous reductants in submerged arc furnaces (SAF). The process is highly electricity-intensive, with specific energy consumption (SEC) typically in the 3.0–4.0 MWh/t range for conventional setups without extensive pre-reduction; energy constitutes the most significant operating cost in South Africa (Ugwuegbu, 2020; FAPA, 2025:83). Furnace stability (tap-to-tap time, electrode control) and off-gas utilisation significantly influence SEC and alloy quality (Letaba & Zulu, 2021; Metix, 2018).

2.7.2 Technology families and efficiency differentials

The literature recognises four dominant routes:

- Conventional AC SAF – adaptable for feeding, high SEC (~up to 4,000 kWh/t) for older lines without pre-reduction (Ugwuegbu, 2020).
- Outokumpu process – pelletising, sintering, and pre-heating lower furnace SEC by shifting reduction to the kiln using off-gas (Ugwuegbu, 2020).
- DC arc furnace – tolerant of fine ores (reduces the need for lumpy feed); however, it often has a higher electric SEC unless integrated with pre-reduction or heat recovery (Ugwuegbu, 2020; Jones, Barcza et al., 2004).
- Premus process – proprietary pre-reduction in rotary kilns and closed-furnace heat integration, widely recognised as the lowest-cost, most energy-efficient industrial route in South Africa (e.g., Lion) with reduced coke use and high recoveries (Ugwuegbu, 2020; Metix, 2018).

In addition to the above technology routes, operational improvements can be attained through advanced furnace power control (e.g., Mintek controllers), slag chemistry optimisation, and data-driven alloy control (e.g., silicon prediction models) which can further improve energy efficiency and product quality outcomes (Jones, Barcza et al., 2004; Cherkaev et al., 2024).

2.7.3 Chrome ore quality and the impact on energy input

South Africa quality vs. other world suppliers

Ore chemistry Cr/Fe ratio, gangue (MgO/Al_2O_3, SiO_2), reducibility, and particle size directly influence furnace SEC, slag volume/temperature, and reductant demand (SAIMM/Mintek, 2004; Ugwuegbu, 2020). South African stratiform seams (LG6, MG1/2, UG2) typically have lower Cr/Fe ratios and different site occupancies (Al^{3+}, Mg^{2+}), which reduce reducibility compared to some Brazilian, Turkish, or Kazakh ores; this may increase SEC unless mitigated by agglomeration and pre-reduction (MDPI/NWU review, 2023). Since South Africa supplies most of the seaborne ore, these quality attributes have system-wide implications for global smelting efficiency and cost (Sciarone, 1998; DMRE, 2007). Beneficiation (e.g., pelletising/sintering) and kiln pre-reduction help lower energy penalties from fines and less favourable gangue, improving permeability and off-gas utilisation (Ugwuegbu, 2020; Metix, 2018).

2.8 Plant Design Efficiencies

2.8.1 Electricity price, availability and utilisation

When comparing the cost of electricity in South Africa to other nations, the price differences become a key factor in being competitive. In 2025, South African industrial tariffs are estimated to be about 50% higher than in China. This gas is expected to grow without reform; load curtailment further reduces utilisation and increases unit costs (FAPA, 2025; ICRA, 2024). South Africa's idle capacity reached approximately 35% in 2024, while Chinese plants generally operate at higher utilisation due to tariff stability and fewer curtailments (FAPA, 2025; ICRA, 2024).

2.8.2 The technology age and process integration

South Africa hosts a plant with advanced Premus technology and leading process control capabilities. Most of the furnaces in South Africa, however, include many older AC SAF lines with limited pre-reduction and heat recovery (Ugwuegbu, 2020; SAIMM/Mintek, 2004). In China, a newer group of units were constructed, and they often combine pre-heating and pre-reduction, larger furnace modules, and integration with reductant supply. With all of this technology, China is highly dependent on imported SA ore, making it sensitive to South African logistics (ICRA, 2024; FAPA, 2025).

2.8.3 Decarbonisation and embedded power

To address tariff and reliability risks, SA producers are pursuing IPP PPAs and embedded renewables; industry plans have identified up to roughly 750 MW of self-generation potential, subject to wheeling and tariff rules (Mining Weekly, 2021; FAPA, 2025).

2.9 New Technology for Smelting ("Direct Smelting")

"Direct smelting" in the context of chrome generally refers to methods which can process fine ores without having the need for expensive agglomeration and/or plasma or DC arc smelting, thereby reducing reliance on lump ore and enabling flexible feedstock (Goff & Denton, 2004; Ugwuegbu, 2020).

Key options include:

- DC plasma/arc smelting of fines – processes concentrate directly, potentially reducing overall costs when agglomeration is limited; energy consumption can be high unless paired with effective pre-reduction and heat recovery (Goff & Denton, 2004; Ugwuegbu, 2020).

- Enhanced pre-reduction combined with closed-furnace integration (e.g., Premus) – proven at an industrial scale in South Africa; often recognised as the lowest SEC and most cost-effective route by utilising kiln pre-reduction and off-gas energy (Ugwuegbu, 2020; Metix, 2018).
- Plasma smelting – reports suggest that plasma's potential to enhance thermal efficiency and process complex feeds; industrial application remains limited in FeCr compared to AC/DC SAF (Prominer, 2025).
- Hydrogen-assisted reduction and low-temperature pelletisation. Research indicates potential to reduce carbon emissions and enhance pellet curing, though challenges remain regarding technical maturity and economic viability for chromite (MDPI/NWU review, 2023).

2.10 Ferrochrome Quality from Different Smelters (South Africa Vs World Competitors)

FeCr is available in various grades, including high-carbon (HC FeCr), charge chrome (typically <56% Cr), and medium- and low-carbon types, with key impurities such as C, Si, P, and S that influence downstream stainless-steel metallurgy (DMRE Handbook, 2013; Laarmann, 2021). Usually, HC FeCr produced by fluxed smelting contains around 50–53% Cr, 4–6% Si, and 6–8% C (SAIMM Journal, 2024). Variations between smelters stem from differences in ore chemistry, fluxing practices, furnace control, and tapping/ladle treatment, resulting in differences in Si and P content and consistency (SAIMM Journal, 2024; SAIMM/Mintek, 2004).

For the production of low-carbon FeCr, controlling the process route and the quality of reductants (such as FeSiCr carbon input) is crucial; case studies show that the primary (~76% contribution) risk of carbon off-grade is mainly caused by carbon introduced through FeSiCr, highlighting the importance of careful reductant handling and slag-free practices (Infacon XIII, Zimbabwe Alloys case). Twenty South African producers, including Samancor, supply charge chrome for a wide range of stainless products, similar to international peers, but impurity control strategies and grade specifications differ by plant and market (Samancor, 2025; SAIMM Journal, 2024).

2.11 Conclusion

This chapter reviewed the literature on the main, interrelated constraints affecting the sustainability and growth potential of South Africa’s ferrochrome smelters. The evidence indicates that competitiveness is shaped by the interaction of energy cost and reliability pressures, logistics constraints, evolving environmental and policy requirements, and global market dynamics. Collectively, the reviewed literature supports the need for coordinated responses rather than isolated interventions.

Importantly, while existing studies and industry reports document the sector’s challenges, there remains limited qualitative evidence that consolidates senior practitioner perspectives across roles and smelter contexts to explain how these pressures translate into operational and strategic decision-making. This gap informs the research design and motivates the methodology described in Chapter 3, which outlines the qualitative case-study approach and thematic analysis used to address the research objectives.

CHAPTER 3

3 Research Methodology

3.1 Introduction

This chapter details the methodological choices that guided the study. Following Creswell's framework, it connects worldview → design → methods to ensure consistency between the research problem, the qualitative approach, and procedures for data collection, analysis, interpretation, and validation (Creswell & Creswell, 2018). The chapter covers: research paradigm, design, researcher role and reflexivity, sampling and participants, recruitment and consent, data collection, data management, analysis, strategies for trustworthiness/validity, ethical considerations, and limitations.

3.2 Research Paradigm (Worldview)

The study adopts a pragmatic worldview. In Creswell's schema, pragmatism is problem-centred and solution-focused, allowing the researcher to choose methods that "work best" for addressing the practical question at hand, without allegiance to any specific philosophical system (Creswell & Creswell, 2018). Given the multifaceted nature of South Africa's ferrochrome sustainability challenge (energy, regulation, technology, and markets), pragmatism supports flexible qualitative approaches to achieve a practical understanding and provide recommendations. This aligns with the study's aims and previous chapters.

3.3 Research Approach and Design

A qualitative approach is employed to "explore and understand the meaning" participants assign to complex, context-dependent problems (Creswell & Creswell, 2018). Within this approach, the study adopts a case study design to develop an in-depth understanding of an integrated system within the South African chrome-smelting sector, drawing on perspectives from multiple stakeholders within their real-world context (Creswell & Creswell, 2018).

3.4 Role Of the Researcher and Reflexivity

In qualitative inquiry, the researcher is the primary tool for data collection and analysis; reflexivity is thus vital (Creswell & Creswell, 2018). The researcher (i) keeps a reflexive journal to reveal assumptions, positionality, and potential influences on interpretation; (ii) notes analytic memos during coding; and (iii) consciously brackets prior operational experience where relevant, to prioritise participants' voices while recognising interpretive co-construction. Reflexive notes are revisited throughout the analysis to check for potential bias and ensure interpretations remain grounded in the data.

3.5 Study Context and Case Boundary

The "case" is limited to South Africa's chrome-smelting industry and the period of fieldwork defined in the study timeline. The inquiry concentrates on challenges affecting sustainability and growth potential, consistent with the research questions, sectoral background, and scope already outlined. The case is bounded by: (i) geography (South Africa), (ii) sector (ferrochrome smelting), (iii) the period of recent industry stress and restructuring, and (iv) the perspectives of senior professionals directly involved in smelter operations and strategy.

3.6 Population, Sampling Strategy and Participants

3.6.1 Population and sampling strategy

The target population for this study comprised experienced professionals working in, or closely with, South African ferrochrome smelters. Given the exploratory, qualitative, and case-study orientation of the research, a non-probability, purposive sampling strategy was adopted. Purposive sampling is appropriate when the researcher seeks information-rich cases rather than statistical representativeness and selects participants based on their ability to illuminate the research questions (Saunders, Lewis & Thornhill, 2009).

Saunders et al. (2009:239) note that purposive sampling is widely used in qualitative and grounded-theory-oriented research, where sampling decisions are guided by the need to obtain cases that can best help answer the research questions and meet the objectives. Within purposive sampling, this study followed a heterogeneous or maximum-variation logic, intentionally including participants occupying different organisational roles and with experience across different smelters, companies and furnace types in South Africa. Saunders et al. (2009:239) describe heterogeneous (maximum-variation) sampling as a strategy that enables the researcher to "describe and explain the key themes that can be observed" across cases that may be quite different, with any patterns that do emerge being "of particular interest and value", and the data also documenting uniqueness.

Although the study uses purposive sampling overall, the recruitment unfolded in three explicit stages:

- Stage 1: Scoping to refine the sampling frame.

An initial scoping engagement was conducted with production personnel to understand KPI-linked operational constraints (e.g., production tons, availability, utilisation) and to identify which stakeholder groups were best positioned to explain the root causes of these constraints. This scoping engagement was used only to refine the sampling frame and was not recorded or analysed as interview data.

- Stage 2: Purposive candidate selection.

Participants were then purposively selected to ensure heterogeneity across roles (production, engineering, environmental, finance, management), furnace types, and organisational contexts, to strengthen cross-perspective comparison.

The unit of analysis is the set of South African ferrochrome smelters and their operating environment, as represented through key informants occupying different roles and working across different plants and companies. This design aligns with the aim and scope of the dissertation as outlined in Chapters 1–2. It allows for both within-case and cross-case analytical comparison between smelters and organisational contexts.

To examine the potential challenges, the initial step was to engage production personnel to identify the operational issues they face. For each operation, key performance indicators (KPIs) must be met for the business to remain financially viable. The goal was to understand their KPIs and whether they are being achieved. The main KPIs to focus on were meeting production forecast targets in terms of tons, plant availability, and plant utilisation. This helped pinpoint where the main problems occur and identify relevant stakeholders to consult for insights into their causes.

If the primary challenge was related to production personnel operating the plant, then production coordinators and metallurgists were interviewed. If the issues stemmed from plant availability due to equipment reliability, personnel from the engineering department, such as coordinators, engineers, superintendents, and engineering managers, were approached. Production departments track and report on all issues that affect their performance at the plant, including monitoring the budgeted cost of production for forecasted tons throughout the financial year. When challenges stemmed mainly from how the smelter was managed, senior management was consulted to gain a clearer understanding of the difficulties they faced.

Qualitative sample size was determined with reference to depth and saturation rather than statistical power. Creswell explains that sample size in qualitative research depends on the chosen design and that in case study research, relatively small numbers of participants can be appropriate, with adequacy judged by thematic saturation, when further data collection no longer yields new insights (Creswell, 2014; Creswell, cited in Creswell & Poth, 2018). Saunders et al. (2009:235) likewise indicate that, while some guidance exists (for example, 12 interviews in relatively homogeneous groups), the emphasis in qualitative interviewing is on validity, understanding and insight, which depend more on the researcher's data collection and analysis skills than on sample size per se.

In this study, the decision to work with a small number of highly experienced, information-rich key informants is thus consistent with established qualitative sampling guidance for exploratory, inductive case research (Creswell, 2014; Saunders et al., 2009). In total, seven participants meeting the inclusion criteria were interviewed, and recruitment ceased once the data provided sufficient depth and no substantially new themes emerged.

3.6.2 Inclusion Criteria

Participants were selected based on the following inclusion criteria:

- several years of professional experience in the ferrochrome or broader smelting industry in South Africa.
- direct involvement in, or responsibility for, smelter operations, production, safety, environmental management, metallurgy or finance.
- experience across different smelters, different companies and different furnace types (for example, exposure to different process technologies and plant configurations within South African chrome smelting).
- willingness and availability to participate in a semi-structured interview conducted via Microsoft Teams.

These criteria ensured that participants were well placed to provide informed, reflective accounts of the operational, economic, regulatory, technological and environmental challenges affecting the sustainability and growth potential of South Africa's ferrochrome smelters, consistent with Creswell's recommendation that qualitative researchers purposefully select "information-rich" participants who can best help understand the central phenomenon under study (Creswell & Poth, 2018).

3.6.3 Participant profile

The final sample consisted of **seven** key informants occupying senior technical, managerial, engineering and financial roles within, or closely linked to, South African ferrochrome smelters:

- Production engineer – responsible for day-to-day furnace and plant performance, optimisation of process parameters and coordination between operations and maintenance.
- HSECQ superintendent and former senior metallurgist – accountable for health, safety, environmental and quality performance, while also drawing on deep metallurgical expertise to link regulatory compliance, product quality and process control.
- Services and production manager – overseeing overall plant output across raw materials, final product, the ISO 17025-accredited laboratory and logistics, including road and rail interfaces with ports.
- General manager – holding strategic and operational responsibility for smelter business performance, including cost management, stakeholder relations, capital allocation and long-term sustainability decisions.
- Financial accountant – providing insight into financial reporting, cost structures, capital investment decisions and economic pressures, including the impact of electricity tariffs, carbon tax and raw-material price movements.
- Production superintendent – managing shift-based furnace operations and production teams, with responsibility for meeting throughput, availability and utilisation targets under conditions of labour downscaling and load curtailment.
- Engineering superintendent – responsible for engineering management of the metal recovery plant, site services and tailings storage facilities, including maintenance of ageing infrastructure, TSF compliance and implementation of technological upgrades.

Collectively, these participants brought multi-perspective, cross-functional insight into the challenges faced by ferrochrome smelters, spanning technical operations, engineering and maintenance, safety and environmental management, strategic leadership and financial performance. Their experience across different smelters, companies, and furnace technologies also supports a maximum-variation logic, enhancing the study's ability to identify both common patterns and context-specific differences in the sustainability and growth challenges of the sector (Saunders et al., 2009).

3.6.4 Recruitment and informed consent

Gatekeeper approval was obtained from one of the top ferrochrome producers in South Africa. A General Manager provided approval after consultation with the company’s COO and their compliance department. This facilitated access to willing participants who shared insights into their experiences with the ferrochrome industry over the years. Prospective participants were approached to determine their willingness to participate in the study. Those who were willing and verbally agreed were notified that participation was voluntary. They were later sent an informed consent form that included the study's purpose, how the gathered information would be used, that their participation was voluntary, and that they had the right to withdraw at any time. Some participants preferred to conduct the interviews first to see how it went before signing the informed consent form. Those participants were accommodated because their participation was voluntary and, as part of the ethics application, should not be perceived as, or made to feel, vulnerable, or placed in a position of discomfort during the research. Others were willing to sign a consent form before the interviews; the signed form was obtained for the collected data, including explicit permission for audio recording or Teams recording. At the beginning of each interview, the contents of the informed consent form were reiterated before interview questions were asked, and participants were reminded that they could withdraw from the study at any time (Creswell & Creswell, 2018).

3.7 Data Collection

3.7.1 Inductive approach

This study employs an inductive approach to data collection and analysis. In inductive logic, the researcher starts with field data and allows patterns, themes, and relationships to emerge rather than testing a priori hypotheses. Saunders et al. (2009:490) explain that when a research project uses an inductive approach, the aim is to "build up a theory that is adequately grounded in the data," typically by collecting and exploring data without imposing a predetermined theoretical framework.

In practice, this means that the study begins with a clear research purpose, but the specific categories and explanations are developed iteratively as data are gathered and analysed. Saunders et al. (2009:489) also note that inductively based procedures seek a good "fit" between the social reality of participants and the theory that emerges, thereby grounding explanation in the participants' own experiences and language.

A grounded-theory-informed perspective complements the inductive approach of this study. The aim was not to develop a complete formal grounded theory, but to apply grounded theory principles to structure an inductive thematic analysis. Creswell and Creswell describe grounded theory as a qualitative design in which the researcher "derives a general, abstract theory of a process, action, or interaction grounded in the views of participants," using multiple stages of data collection and refining interconnected categories of information (Creswell & Creswell, 2018). Similarly, Saunders et al. (2009:490) characterise an inductive, grounded approach as one in which the researcher does not start with a detailed theoretical framework but instead identifies relationships in the data and allows theory to "emerge from the process of data collection and analysis."

Consistent with these descriptions, this study does not test a fixed model of the challenges affecting ferrochrome smelters; instead, it uses interview and document data to inductively develop categories and propositions that are grounded in participants' lived experiences at the plant level (Creswell & Creswell, 2018; Saunders et al., 2009).

3.7.2 Case study design and bounded context

The data collection strategy is embedded in a **qualitative case study design**. Case study research involves an "exhaustive and comprehensive evaluation of a specific situation, event, social group or organisation," where the case is understood as "a phenomenon of some sort in a bounded context" defined by space and time (Bunkar et al., 2024:68).

In this study, the "case" is the set of South African ferrochrome smelters selected for investigation, bounded by their organisational context, operating environment and the recent period of industry stress and restructuring.

Creswell and Creswell (2018) describe case studies as a research design in which the researcher conducts an in-depth analysis of a case, such as a programme, event, activity, process, or one or more organisations, bounded by time and activity, and explored through multiple sources of information over a sustained period.

Bunkar et al. (2024:68) similarly emphasise that case study research is particularly suited to exploring complex phenomena in real-world contexts, where context and phenomenon are closely intertwined and require holistic analysis.

In line with these definitions, this study uses a case study design to generate rich, contextualised data on operational, economic, regulatory and environmental challenges in chrome smelting. Purposeful selection of plants and participants allows the researcher to obtain multiple perspectives within the bounded organisational and industry context, which is consistent with the view that case studies rely on in-depth, contextually anchored evidence from several sources (Bunkar et al., 2024:68; Creswell & Creswell, 2018).

3.7.3 Data collection method - Semi-structured interviews

Within this inductive, case study- and grounded theory–informed design, semi-structured qualitative interviews are the primary data collection method, supported by relevant documents (e.g., company reports, industry publications, and regulatory texts). Saunders et al. (2009:324) argue that interviews are particularly advantageous when there are many questions, when questions are complex or open-ended, and when the order and logic of questioning must remain flexible. These conditions apply in this study's exploration of smelter challenges. Non-standardised, qualitative interviews (semi-structured and in-depth) allow the researcher to collect "a rich and detailed set of data," especially when exploring topics or explaining earlier findings (Saunders et al., 2009:351).

Semi-structured interviews, in particular, support the use of an interview guide while still enabling the researcher to probe, clarify and adapt questions based on participants' responses, which is essential when working inductively and seeking participants' own meanings (Creswell & Creswell, 2018; Saunders et al., 2009:324–325, 351–352). The interview guide is aligned with the research questions but remains sufficiently open to capture unexpected themes and processes that can inform grounded-theory-style category development. Creswell and Creswell (2018) note that qualitative researchers typically "work inductively, building patterns, categories and themes from the bottom up" by organising data into increasingly abstract units of information, moving back and forth between the database and emerging themes (Creswell & Creswell, 2018). This study applies that logic by coding interview transcripts and documents iteratively, allowing categories related to sustainability challenges and growth constraints to emerge rather than forcing them into pre-specified codes.

In addition to interviews, the case study design promotes the use of multiple sources of evidence, such as observations, documents, and archival records, to deepen contextual understanding and strengthen the credibility of findings (Bunkar et al., 2024:68; Creswell & Creswell, 2018). Triangulating interview data with documentary materials supports more nuanced, inductively grounded explanations of how macro-level pressures translate into plant-level operational realities in South African ferrochrome smelters.

In practice, the semi-structured interviews in this study were conducted via Microsoft Teams, which has proven to be a reliable and cost-effective platform for audio recording and transcription in both online and face-to-face contexts. Interviews typically lasted around one hour. At the start of each interview, the researcher verbally revisited the key elements of the consent form, reminding participants that participation was voluntary, that they could withdraw at any time without penalty and that they were free to decline to answer any question. Participants were also reminded that the sessions would be recorded via Microsoft Teams for transcription purposes and that their identities would be concealed in all reports. Once consent for recording was confirmed, sessions were audio-recorded and later transcribed verbatim. Field notes were taken to capture contextual and behavioural observations that could complement the transcripts during analysis.

Some initially identified individuals withdrew from the study before interviews could take place, most commonly citing time constraints. In keeping with the purposive, information-rich sampling logic, recruitment continued until an adequate spread of senior roles and smelter experience had been achieved, at which point data collection ceased.

3.7.4 Interview guide

The questions used to initiate the semi-structured interviews were sent to the participants beforehand. The guide examines operational, economic, regulatory, environmental, technological, and stakeholder-collaboration challenges, along with suggestions for improvement, thus reflecting the topical coverage of Chapters 1–2 and the main research question (Creswell & Creswell, 2018).

3.8 Data Management

Data management procedures in this study were designed to ensure that all qualitative data generated through Microsoft Teams recordings and transcripts were handled systematically, securely, and ethically. Transcripts and recordings done via Microsoft Teams are available for both the researcher and participants. In line with Creswell and Creswell's (2018) guidance on qualitative method sections, the procedures for recording, storing, organising and preparing data for analysis were planned in advance as part of the overall research design, including specification of data collection forms and recording protocols.

3.8.1 Audio-recordings via Microsoft Teams

Interviews conducted face-to-face were also recorded and transcribed using Microsoft Teams and were made available only to the relevant study participant. Transcripts were de-identified, assigned participant codes, and stored in encrypted or password-protected folders accessible only to the researcher. A structured data management log documents files, storage locations, and retention or disposal actions, in accordance with good practice for qualitative projects as described by Creswell (Creswell & Creswell, 2018).

3.8.2 Transcription, anonymisation and file organisation

Following the guidance of Saunders et al. (2009) on preparing qualitative data, all Teams audio recordings were transcribed verbatim into separate word-processed files as soon as possible after each interview. Saunders et al. (2009:485) emphasise that non-standardised qualitative interviews are usually audio-recorded and subsequently transcribed into a written account using participants' actual words. That transcription should be completed promptly to avoid a buildup of recordings and workload.

To ensure confidentiality, each transcript was saved as an individual file using a coded filename that did not contain participants' real names or organisational identifiers, in line with recommendations by Saunders et al. (2009:485) that transcripts be stored as separate files with filenames that "maintain confidentiality and preserve anonymity" while still being recognisable to the researcher.

A separate password-protected master list linking codes to participants' identities was maintained and stored independently from the transcripts. Any direct identifiers (names of individuals, specific departments, or highly sensitive operational details) were removed or replaced with pseudonyms during transcription to protect anonymity.

Transcripts were also checked for accuracy and data cleaning, consistent with Saunders et al.'s (2009:485) recommendation that transcription errors be corrected and records prepared carefully before analysis. Where necessary, minor clarifications were added in brackets to preserve meaning without altering participants' intended responses.

3.8.3 Secure storage, backup and retention

All electronic data (Teams audio files, transcripts and the pseudonym key) were stored on a password-protected computer and encrypted cloud storage accessible only to the researcher and, where required, the academic supervisor. File structures followed the suggestion of Saunders et al. (2009:485) to maintain project-specific folders and subdirectories so that transcripts are organised and easily identifiable for later analysis.

Creswell and Creswell (2018) emphasise anticipating ethical issues at the stages of collecting, analysing, reporting and storing data. Data management procedures were aligned with the ethical clearance obtained from the university and with institutional requirements on secure storage and responsible handling of qualitative data.

Data will be retained for the period prescribed by the university (e.g., a minimum of 5 years after completion of the study) and thereafter permanently deleted from all storage devices. No data will be shared with third parties in an identifiable form; any secondary use of the dataset will rely solely on de-identified material.

These procedures collectively ensure that the Microsoft Teams recordings and their derived transcripts were systematically managed, ethically safeguarded and analytically usable throughout the research lifecycle, in line with established qualitative research guidance (Creswell & Creswell, 2018; Saunders et al., 2009).

3.9 Data Analysis

Data analysis followed an inductive, thematic approach informed by grounded theory techniques (e.g. constant comparison and iterative coding), without seeking to construct a complete grounded theory. The aim was to move from detailed interview accounts of operational, economic, regulatory, technological and environmental challenges in ferrochrome smelters to a set of higher-order categories and themes that explain the factors affecting smelter sustainability and growth. Qualitative data analysis was treated as an ongoing, iterative process rather than a single linear step, beginning during data collection and continuing through coding, theme development and interpretation (Creswell & Creswell, 2018). Interview scripts had to be polished or cleaned up first because Microsoft Teams transcription is not accurate when constructing sentences. Participants' names were replaced with initials, such as GM (General Manager), FA (Financial Accountant), and PM (Production Manager). The file names were P1-P7 for each participant's transcripts. Interview transcripts were then imported into ATLAS.ti, including the use of its Atlas AI functions, to assist with systematic coding, retrieval and organisation of codes, memos and emerging categories.

In line with Creswell's guidance, this process involved (i) organising and preparing the data, (ii) reading through the information to gain an overall sense, (iii) coding the data, (iv) developing description and themes from the codes, (v) using computer programs to assist analysis, and (vi) interpreting the findings in relation to prior literature and theory.

3.9.1 Preparation and familiarisation

All Microsoft Teams audio recordings were first transcribed verbatim and checked against the audio files to ensure accuracy. Transcripts were then cleaned by correcting obvious transcription errors while retaining participants' meaning. Consistent with Creswell and Creswell (2018), the researcher then organised and prepared the text data for analysis and repeatedly read the transcripts to develop an overall understanding of participants' experiences before formal coding commenced.

This familiarisation phase enabled the researcher to identify preliminary issues (such as electricity pricing, energy reliability, logistics bottlenecks, regulatory uncertainty, and environmental compliance) and to sensitise the analysis to both convergent and divergent patterns across smelters.

3.9.2 Inductive coding and grounded theory–informed procedures

Coding proceeded inductively, allowing codes and categories to emerge from the participants' language rather than imposing a priori theoretical constructs. This aligns with Creswell's view that qualitative coding typically progresses from specific segments of text to more general themes, often culminating in a relatively small number of core themes (approximately five to seven) that represent the study's significant findings (Creswell & Creswell, 2018).

The coding process was grounded theory-informed, drawing on ideas from Strauss and Corbin (e.g., open and selective coding), but applied flexibly to support inductive thematic analysis rather than the development of a formal grounded theory. In grounded theory terms, the first stage involved open coding, during which the interview transcripts were broken down into meaningful units (words, phrases, sentences or short paragraphs) and labelled with conceptual codes that reflected participants' meanings (Strauss & Corbin, cited in Saunders et al., 2009:509). Codes were derived primarily from the data (including "in vivo" codes using participants' own wording), rather than from pre-existing theory, consistent with an inductively based analytical procedure (Saunders et al., 2009:509).

As coding progressed, similar codes were compared and grouped into broader categories, reflecting the constant comparative logic of grounded theory, where data segments are continually compared with emerging concepts and categories to refine their meaning and scope (Strauss & Corbin, cited in Saunders et al., 2009:511). This stage approximates axial coding, in which relationships between categories are explored and arranged hierarchically to explain "what is happening and why" in the phenomenon under investigation (Saunders et al., 2009:511).

Although the study did not aim to produce a fully elaborated substantive theory, aspects of selective coding were incorporated in a grounded-theory-informed thematic analysis, by progressively focusing on a smaller set of central categories that appeared to organise and integrate the emerging findings (for example, energy insecurity, policy and regulatory instability, structural cost pressures, and operational constraints). This is consistent with descriptions of grounded theory where open, axial and selective coding are used to build an explanation around a core theme emerging from the data (Strauss & Corbin, cited in Saunders et al., 2009:509).

3.9.3 Development of categories and themes

Following initial open coding, categories were refined through multiple cycles of comparison and data "winnowing." Creswell notes that qualitative data are typically dense and that researchers must focus on the most salient information, aggregating codes into a manageable number of themes that can adequately represent the phenomenon (Creswell & Creswell, 2018).

In this study, overlapping or redundant codes were collapsed and organised into broader categories, such as:

- structural electricity cost and reliability risks,
- logistics and infrastructure constraints,
- environmental and carbon-regulation pressures,
- labour and community-related dynamics, and
- strategic adaptation and investment decisions.

These categories were then further abstracted into higher-order themes that served as the main analytical lenses in the findings chapter. Consistent with Creswell's guidance, these themes were treated as the primary qualitative "findings" and are presented as major headings in the results, supported by multiple quotations and detailed descriptions to display the range of perspectives expressed by participants (Creswell & Creswell, 2018).

3.9.4 Within-case and cross-case analysis

Because the research adopted a multiple-case study design focusing on different ferrochrome smelters, data analysis proceeded at two levels. First, within-case analyses were conducted for each smelter, organising codes and categories into case-specific themes to preserve contextual depth. Second, a cross-case analysis compared themes across smelters to identify commonalities and differences in the challenges affecting sustainability and growth. This is consistent with Creswell's suggestion that, in qualitative case study research, themes can be analysed for each case and then examined across cases to build more complex explanations (Creswell & Creswell, 2018).

3.9.5 Representation and interpretation

Finally, the refined themes were presented in a narrative format, supported by illustrative quotations and, where appropriate, summary tables that showed how categories and themes related to the research questions. Creswell emphasises that qualitative findings are often best presented through rich narrative passages that discuss key themes, subthemes, multiple perspectives and interconnections between themes (Creswell & Creswell, 2018).

Interpretation involved moving beyond description to explain the implications of the themes for the sustainability and growth potential of South Africa's ferrochrome smelters, and to relate the findings to the literature and conceptual framing of the study. In line with Creswell's view of qualitative analysis, interpretations also included reflections on lessons learned, comparison with existing theory and prior research, and indications of where future research could further refine or extend the emerging explanations (Creswell & Creswell, 2018).

3.10 Reliability, validity and trustworthiness

Ensuring the quality of findings is essential in qualitative, inductive case study research. In this study, reliability, validity and trustworthiness are addressed in line with Creswell's guidance on qualitative validity and reliability (Creswell, 2014), Saunders et al., (2009)'s discussion of data quality in non-standardised interviews (Saunders et al., 2009), and case study–specific criteria proposed in the case study literature (Yin, 2014; Bunkar et al., 2024).

3.10.1 Qualitative validity

Creswell (2014) defines *qualitative validity* as the process by which the researcher assesses the accuracy of the findings through specific procedures, distinguishing it from quantitative notions of validity, reliability, and generalisability. Validity in this sense centres on whether the findings are accurate from the standpoint of the researcher, participants and intended readers. Terms such as *trustworthiness*, *authenticity* and *credibility* are widely used in the qualitative literature as closely related concepts (Creswell & Miller, 2000; Lincoln, Lynham & Guba, 2011).

In this study, several of Creswell's recommended validity strategies are integrated into the research design. First, triangulation is pursued by comparing interview accounts across multiple participants and, where available, with organisational documents or contextual information. Triangulating across different data sources enables the researcher to build a coherent justification for emergent themes, thereby enhancing validity (Creswell, 2014). Second, member checking involves sharing a summary of key themes and interpretations with selected participants and inviting them to provide feedback on whether these adequately reflect their experience, which Creswell considers a central procedure for assessing the accuracy of qualitative findings.

Third, the findings are presented through rich, thick descriptions of the case context and participants' perspectives, which allow readers to "enter" the setting and decide how transferable the results are to other contexts (Merriam, 1988; Creswell, 2014). Fourth, the researcher engages in reflexivity by explicitly acknowledging prior professional experience in the ferrochrome sector and reflecting on how this background may shape interpretations, as recommended by Creswell's emphasis on clarifying researcher bias. Finally, negative or discrepant evidence that does not align with dominant themes is actively sought out and reported, thereby strengthening the account's credibility and realism.

Case study–specific validity concerns are also recognised. External validity in case studies relates to the degree to which findings can be generalised to other contexts. Yin (2009) and Bunkar et al. (2024) argue that case studies do not rely on statistical generalisation from samples, but rather on *analytic generalisation* to theory; external validity is therefore enhanced by clearly linking case findings to broader theoretical propositions and by replicating the study's logic across cases where possible.

Internal validity is addressed by carefully considering and minimising alternative explanations or extraneous factors that could account for the observed outcomes in the case (Yin, 2014).

3.10.2 Reliability in qualitative case study research

In qualitative research, reliability refers to the consistency or stability of the research procedures, rather than the exact replicability of findings as in quantitative designs. Creswell (2014) emphasises that qualitative reliability concerns the degree to which a researcher's approach is consistent across different researchers and projects, and recommends clear documentation of procedures and codebooks, as well as the checking of transcripts and codes (Gibbs, 2007; Yin, 2009).

Saunders et al. (2009) similarly note that the lack of standardisation in semi-structured interviews can raise concerns about reliability; in this context, reliability is understood as whether other researchers would yield similar findings in comparable settings. They highlight the importance of managing interviewer bias (e.g., through neutral questioning, non-leading probes, and careful interpretation) and interviewee bias (e.g., socially desirable responses or partial disclosure), as these can undermine the reliability and validity of qualitative interview data.

To support reliability in this case study, several strategies are implemented:

- A semi-structured interview guide is developed and consistently used across interviews, ensuring that core topics are addressed while allowing flexibility to probe context-specific issues, in line with the case study guidance that field procedures and question sets should be specified in a case study protocol (Yin, 2014).

- All Microsoft Teams interviews are audio-recorded and transcribed verbatim, and transcripts are checked for obvious errors, as recommended by Gibbs (2007) and Creswell (2014) for qualitative reliability.

- Coding procedures are documented in a coding framework, with iterative comparison of data and codes to avoid "drift" in code meanings over time. This aligns with Creswell's suggestion that researchers continually compare data with codes and record memos to stabilise definitions.

- A clear audit trail of decisions on case selection, data collection, coding, and theme development is maintained so that other researchers can follow the study's logic and procedures, echoing Yin’s call for detailed case study protocols and databases to enhance reliability.

Within the case study methodology, reliability is thus conceptualised as the extent to which the same case study procedures, applied to the same case, would yield comparable findings, given similar conditions (Yin, 2014:100).

3.10.3 Trustworthiness: credibility, transferability, dependability and confirmability

Following Lincoln and Guba’s (1985) influential framework, *trustworthiness* in qualitative research is typically discussed in terms of credibility, transferability, dependability and confirmability. Creswell and Miller (2000) note that concepts such as trustworthiness, authenticity and credibility are widely used as qualitative counterparts to traditional notions of validity and reliability.

- Credibility corresponds broadly to internal validity and concerns whether the findings are believable and accurate from the participants’ perspective. In this study, credibility is enhanced through triangulation of multiple participants, member checking, prolonged engagement with the data, peer debriefing with the academic supervisor, and the presentation of discrepant evidence, as recommended by Creswell’s list of verification strategies.

- Transferability parallels external validity and refers to the degree to which findings may be applicable in other contexts. Rather than claiming statistical generalisability, the study provides a rich, thick description of the smelter context and organisational conditions, thereby allowing readers to judge the extent of transferability to similar ferrochrome operations or energy-intensive process industries (Merriam, 1988; Yin, 2009).

- Dependability corresponds to reliability and concerns the stability of data over time and across conditions. Dependability is supported by documenting the research design, interview procedures, data management processes, and coding decisions in detail, and by using method triangulation to strengthen both reliability and internal validity.

- Confirmability relates to the degree to which the findings are shaped by the participants and the phenomena under study, rather than by researcher bias or predispositions. Confirmability is enhanced through reflexive accounts of the researcher’s role and assumptions, systematic documentation of analytic decisions, and, where feasible, external or peer review of the analysis process, as Creswell recommends via peer debriefing and external auditing.

Collectively, these procedures demonstrate that the study is designed to achieve methodological rigour appropriate to an inductive, qualitative case study. By integrating Creswell's validation strategies, Saunders et al., (2009)'s treatment of interview data quality, and case study–specific guidance on validity and reliability (Yin, 2014; Bunkar et al., 2024), the research aims to produce findings that are credible, dependable, transferable and confirmable, and thus trustworthy within the context of South Africa's chrome smelter industry.

3.11 Ethics And Ethical Considerations

Ethical issues were considered at all stages of this qualitative case study, from planning and gaining access to participants through to data collection, analysis, reporting and data storage. Creswell emphasises that researchers must anticipate ethical issues throughout the research process, because research involves "collecting data from people, about people," and therefore requires protecting participants, building trust, promoting the integrity of research, and guarding against misconduct (Creswell & Creswell, 2018). Ethical considerations apply to qualitative, quantitative and mixed-methods research and should be addressed before beginning the study, during data collection and analysis, and when reporting and storing data (Creswell & Creswell, 2018).

3.11.1 Institutional approval and access

Prior to data collection, the study protocol, including the interview guide, informed consent procedures and data management plan, was submitted for review and approval by the university's research ethics committee in line with institutional requirements. Creswell notes that researchers should submit their research to an institutional review board (IRB) or equivalent ethics committee, which evaluates potential risks (physical, psychological, social, economic, or legal) and ensures that participants' rights are protected (Creswell & Creswell, 2018).

Access to participants was negotiated transparently through professional networks and organisational gatekeepers. Following Saunders et al., (2009), the researcher clearly communicated the purpose of the research, the expected time commitment, data collection procedures, confidentiality arrangements, and potential benefits to the participating organisations and individuals, as would be set out in a participant information sheet (Saunders et al., 2009).

3.11.2 Informed, voluntary participation

Participation in the study was strictly voluntary. Potential participants received an information sheet and a consent form outlining the nature and aims of the study, what participation would involve, the use and storage of data, and their rights as participants. Saunders et al. (2009:190) stress that consent is not straightforward and ranges along a continuum from lack of consent to fully informed consent; they argue that ethical practice requires consent that is “freely given” and based on “full information” about participation rights and the use of data.

In line with their checklist for participant information sheets, participants were informed that participation was voluntary, that they had the right to decline to answer any question, and that they could withdraw from the study at any time without penalty (Saunders et al., 2009:191). The consent process also emphasised that participants retained control over the audio recording of interviews and that their decision to participate or not would affect their employment relationship. Measures to avoid coercion included ensuring that no financial inducements were offered and that managers or gatekeepers did not pressure participants to participate, consistent with Saunders et al.’s (2009) guidance on avoiding pressure to participate. Signed consent forms were obtained from all participants before interviews were conducted via Microsoft Teams.

3.11.3 Confidentiality, anonymity and privacy

The study was designed to protect participants’ confidentiality and anonymity. Saunders et al. (2009:589) define confidentiality as concerns relating to the right of access to data provided by participants and the need to keep these data secret or private, and emphasise the importance of informed consent and explicit assurances on anonymity and data use.

In this study:

- Participants were assigned pseudonyms or generic role descriptors (e.g. “Production manager,” “General manager,” “Financial accountant”) in all transcripts, notes and reports.
- Identifying details such as company names, smelter locations or specific project references were removed or generalised where necessary to prevent indirect identification.
- Only the researcher (and, if required, the academic supervisor) had access to raw audio files and full transcripts.

These measures were communicated in the information sheet, which also explained who would have access to the data, how results would be disseminated, and what would happen to the data after project completion, in line with the requirements listed in Saunders et al.'s (2009) participant information checklist.

3.11.4 Minimising risk and protecting participants

Creswell emphasises that researchers must protect participants, develop trust, promote research integrity and guard against misconduct and impropriety that might reflect on their organisations or institutions (Creswell & Creswell, 2018).

In this study, potential risks were assessed as minimal, given that participants were experienced professionals discussing their work context rather than vulnerable individuals. However, the following steps were taken to minimise possible **psychological, social or economic risks**:

- Questions were framed to focus on **processes, challenges and responses** rather than on individuals' personal performance or confidential corporate strategies.
- Participants were reminded that they could skip any question they did not feel comfortable answering.
- Findings are reported in aggregated form and with role-based descriptors rather than names, reducing the likelihood that statements can be traced back to a specific person or organisation.

These measures align with guidance that ethics involve consideration of privacy, confidentiality, anonymity, informed consent and levels of research risk (Creswell & Creswell, 2018).

3.11.5 Ethical handling, reporting and storage of data

Ethical responsibilities also extend to how data are **stored, analysed, reported and archived**. Creswell notes that ethical issues arise not only before and during data collection, but also in data analysis and in the reporting, sharing, and storage of data (Creswell & Creswell, 2018).

As described in the data management section, all Microsoft Teams recordings and transcripts were stored on a password-protected computer and encrypted cloud storage, accessible only to the researcher and, where necessary, the supervisor. Data were organised in coded folders so that individual participants could not be identified from filenames. These arrangements mirror Saunders et al.'s (2009) recommendation that researchers specify who will have access to collected data, how anonymity and confidentiality will be maintained at the reporting stage, and what will happen to data after completion, including safeguards for any preserved data.

Data will be retained for the period stipulated by the university's policy (for example, a minimum of five years after completion of the study), after which electronic files will be permanently deleted.

No raw data will be made publicly available in identifiable form; any future use will rely on fully anonymised material.

3.12 Practical steps taken during the research

In practice, the research unfolded through a series of concrete steps that operationalised the methodological choices described above. After obtaining ethical clearance from the university and gatekeeper approval from a major ferrochrome producer, the researcher used professional networks and internal referrals to identify experienced participants who met the inclusion criteria. The prospective participants were contacted by phone, and a brief discussion was held to inform them about the research I am conducting and to see if they would be interested. Consent forms were emailed to prospective participants who had indicated their willingness to participate, and interviews were scheduled at times that fit with their operational responsibilities. Although some showed interest, they cancelled at the last minute. Seven interviews were conducted via Microsoft Teams, typically lasting about an hour, using the semi-structured guide to ensure that key topics such as operational, economic, energy constraints, regulatory and environmental challenges, technology, and stakeholder dynamics were covered while still allowing participants to narrate their own experiences. With participants' permission, the interviews were recorded, downloaded and saved under neutral codes (P1–P7), transcribed verbatim and then cleaned to correct obvious transcription errors and remove identifying details. From the fifth participant, no new data was found. By the seventh participant, data saturation was reached. The anonymised transcripts were imported into ATLAS.ti, where an inductive, grounded-theory-informed coding process was followed: initial open coding generated numerous descriptive codes, which were progressively grouped into broader categories and refined through constant comparison and memo writing into the eight overarching themes presented in Chapter 4. Throughout this journey, the researcher kept field notes and a reflexive journal and engaged in regular discussions with the academic supervisor to check emerging interpretations against the raw data, thereby ensuring that the methodological framework was rigorously applied in practice.

3.13 Summary

Guided by Creswell's design logic, this chapter justified a pragmatic qualitative case study with purposive sampling, semi-structured interviews, inductive thematic analysis, and robust strategies for validity and ethics. Practical steps taken in the field, including gaining access, were outlined, as were conducting Microsoft Teams interviews, transcribing, anonymising, and coding the data in ATLAS.ti. These choices directly support the study's aim: to generate actionable, context-sensitive insight into the sustainability and growth challenges facing South Africa's ferrochrome smelters.

CHAPTER 4

4 Findings and analysis

4.1 Introduction

This chapter presents findings from semi-structured interviews with senior professionals in the South African ferrochrome smelting industry. Consistent with the qualitative, inductive and case study design outlined in Chapter 3, the analysis focused on understanding how operational, economic, regulatory, technological and environmental challenges affect the sustainability and growth potential of South Africa's ferrochrome smelters.

Using an inductive, grounded-theory-informed thematic analysis supported by computer-assisted qualitative data analysis software, interview transcripts were coded and compared across cases to identify recurring patterns and salient differences. The chapter starts by outlining the profile of participants and summarising the process of theme development.

There are eight main themes presented, which are:-

1. Cost structure and economic pressures
2. Energy crisis, electricity tariffs and supply instability
3. Raw materials, logistics and infrastructure constraints
4. Global competition, China and ore export dynamics
5. Regulatory, environmental and health, safety and environment pressures
6. Technology, automation and skills
7. Stakeholders, communities and social licence to operate
8. Strategic responses and recommendations.

Throughout this chapter, the participants are referred to by role-based descriptors and codes to preserve anonymity while signalling their positions and perspectives, such as coding Production engineer – P1 and HSECQ superintendent – P2.

4.2 Participant Profile

Seven experienced professionals participated in the study, reflecting a deliberate maximum-variation sampling strategy across roles, companies and smelter types. All participants had 13 to 25 years of experience in the ferrochrome smelting industry and had worked at more than one operation during their careers. This provided cumulative insight into how industry conditions and operational challenges have evolved. Data saturation occurred after five participants, but two additional participants were interviewed to ensure saturation.

The production engineer (P1) is responsible for furnace and plant performance at one of the major ferrochrome producers, focusing on volumes, quality, and safety, and reporting on inputs to the cost of production (COP) at the core of the smelting process. The person has 18 years of work experience across various smelters and plants in the ferrochrome industry.

The HSECQ superintendent and former senior metallurgist (P2) combined responsibility for health, safety, environment, quality and metallurgical performance, thereby linking regulatory compliance, product quality and process control. The person has 16 years of experience in the ferrochrome industry, 13 years in production, serving as a junior to senior metallurgist at company X, and is currently working as an HSECQ superintendent at company Y, focusing on health, safety, environment, community, and quality compliance.

The services and production manager (P3) oversees the raw material plant, final product plant, the ISO 17025-accredited laboratory and logistics, including interfaces with both road and rail. The participant is responsible for managing the logistics of sourcing the volumes and quality of raw materials needed for the site to produce ferrochrome. The laboratory verifies the quality of the raw materials received, which is crucial for the furnaces' input process, and also tests and issues certificates for the ferrochrome dispatched. P3 also manages parcel logistics from the marketing department for dispatching the required quantities of ferrochrome and the required quality to both local and export customers. The participant has 16 years of experience in the ferrochrome industry across various ferrochrome smelters (Open and submerged furnaces).

At a more strategic level, the general manager (P4) is accountable for overall smelter performance, including cost control, stakeholder relations, and long-term sustainability decisions. The general manager's role reports directly to the organisation's COO. The participant has 25 years of experience in the ferrochrome industry and has worked in several smelters (Open and submerged furnaces) across three ferrochrome companies in South Africa. P5 has worked as a general manager at companies X and Y across different operations for over 8 years combined and has also been an active participant in the Ferro Alloy Producers Association (FAPA).

Complementing this, the financial accountant (P5) provided detailed insight into cost structures, financial reporting, capital investment decisions, and the impact of electricity tariffs, the carbon tax, and raw-material prices on smelter viability. P5 is a chartered accountant by profession and has had 13 years of experience in the ferrochrome industry.

On the operational side, the production superintendent (P6) manages shift-based furnace operations and production teams, with the responsibility to achieve throughput, plant availability and utilisation targets under conditions of continuing labour downsizing and load curtailment. The participant has 13 years of industry experience across different plants. Finally, the engineering superintendent (P7) oversees engineering management of the metal recovery plant, services and tailings storage facilities (TSFs). P7 has worked in the ferrochrome industry for over 19 years for Company X and Company Y.

Together, these participants have provided a multi-perspective view of the industry, spanning across operational, engineering, safety, financial and strategic dimensions. Their experience across different smelters, companies, and furnace technologies strengthens the findings by allowing both convergent patterns and context-specific nuances to be identified.

4.3 Overview of data analysis and theme development

As outlined in Chapter 3, the interview data were analysed inductively using a grounded-theory-informed thematic approach. Transcripts were first read in full to gain an overall sense of participants' experiences. Initial open coding was then conducted line-by-line, generating a large number of descriptive and in vivo codes reflecting participants' language about cost pressures, energy constraints, regulatory changes, technological developments and stakeholder dynamics. Figure 7 below shows how Atlas.ti was used for coding and theme development.

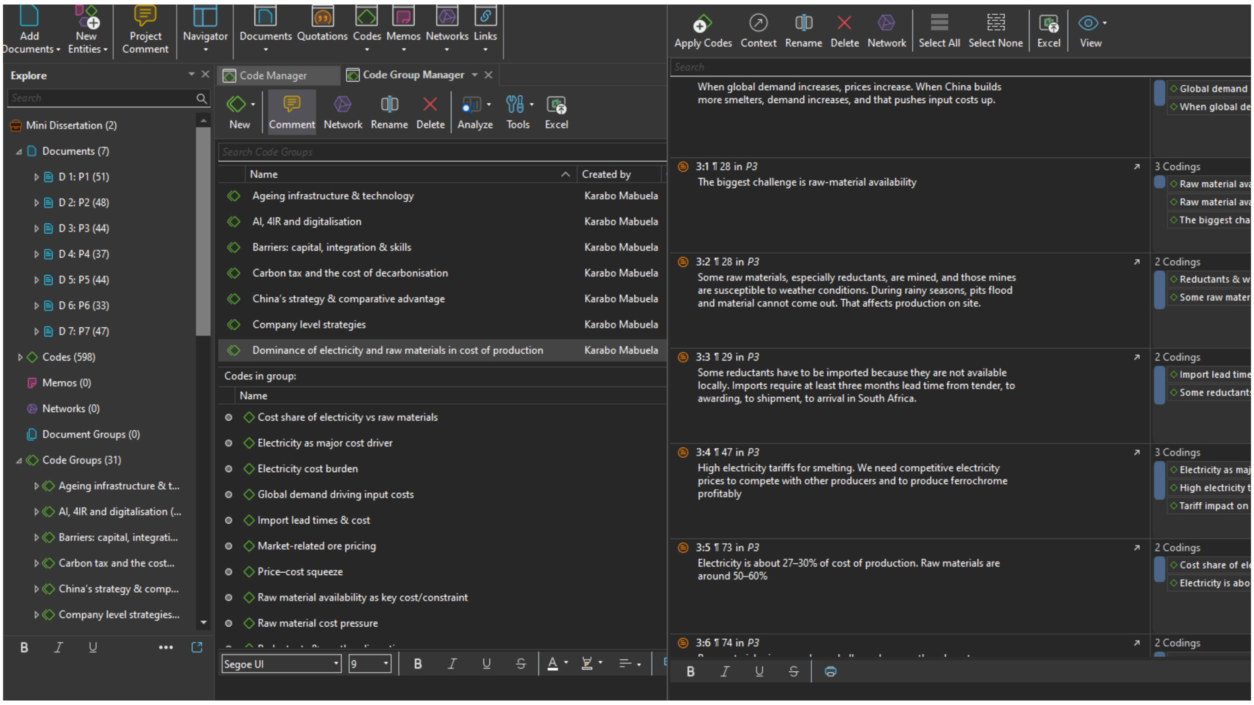


Figure 7: Atlas.ti coding

Through successive cycles of data comparison and sorting, conceptually similar codes were grouped into broader categories such as electricity cost and reliability, raw materials and logistics constraints, environmental and carbon regulations, labour and community issues, and strategic adaptation. This data was analysed further, and a cross-case analysis was used to compare categories across all seven interviews to identify common themes and role- or plant-specific differences.

By the sixth and seventh interviews, no new substantive categories were identified; instead, additional data reinforced and elaborated the existing patterns, indicating that thematic saturation had been achieved for this study.

This process provided eight overarching themes that together capture the key challenges affecting the sustainability and growth potential of South African ferrochrome smelters. These themes are presented below as major sections, each with subthemes that highlight specific aspects of the broader pattern. Within each theme, findings are discussed with reference to the different roles (P1–P7), and the interpretation begins to link the empirical patterns to the conceptual issues raised in Chapters 1 and 2.

4.4 Cost Structure and Economic Pressures

4.4.1 Dominance of electricity and raw materials in the cost of production

Across all interviews, participants emphasised that ferrochrome smelting is an energy- and resource-intensive process, with electricity and raw materials accounting for the majority of production costs. All participants noted that these two components account for the majority of production costs. Firstly, raw material costs are the largest expense, followed by electricity, which also accounts for a substantial share of total production costs. **P3** stated that electricity "*can be about 27 to about 30% in terms of the COP," and 50 to 60% is made up of the ore of the raw materials. The raw materials are also a challenge because they are not coming in cheaper, and we are also using market-related ore pricing*". **P2** reiterated that "*The second challenge is raw-material prices. Ore prices increase, reductant prices increase, coke prices increase. When global demand increases, prices increase. When China builds more smelters, demand increases, and that pushes input costs up*". Next to the raw materials, **P4** also reiterated that "*Electricity is the main ingredient of any ferroalloys process*" and that "t*he biggest challenge is electricity price. Electricity is the main ingredient of any ferroalloy process. Even the most efficient process uses electricity as its biggest cost component*". Participants described a context in which rising electricity tariffs, ore prices and reductant costs have progressively eroded margins, especially when ferrochrome market prices are depressed.

From a financial perspective**, P5** explained that smelters operate with relatively thin margins even under favourable conditions, and that sustained increases in input costs quickly render operations unprofitable. From his perspective, "*Operations need to keep local production costs as low as possible to maintain profit margins. When global prices decrease, the pressure on operations to maintain a low-cost base increases. If an operation cannot sustain a lower cost base, profitability and sustainability are at risk*". Operational participants (P1 and P6) echo the same, reporting that they are under constant pressure to meet production targets while containing costs per ton. Yet, many of the most significant cost components, such as electricity tariffs and the international prices of reductants, are beyond plant-level control.

4.4.2 Escalating fixed, labour and maintenance costs

In addition to electricity and raw materials, participants highlighted escalating labour, maintenance, and fixed overhead costs as key economic pressures on ferrochrome smelters. At a strategic level, P4 emphasised that, after electricity, fixed and salary-related costs are the next significant burden, explaining that "the biggest would be salaries, of course and fixed cost in that order exactly after your electricity prices, the fixed cost, which inside the fixed cost, there's a salary. There's a salary component, and remember everything else in the cost structure goes up with inflation every year, but the pricing doesn't follow inflation at all". He further explained that these fixed elements tend to increase steadily over time, even when ferrochrome prices do not, contributing to the overall squeeze on margins.

Looking at this from an engineering and asset-management perspective, **P7** described how the way maintenance and shutdowns are structured in the industry elaborates on fixed-cost pressure, particularly labour costs during extended shutdown periods. He explained that being unable to share resources for shutdowns lead to costs being over inflated by contractors as he said "*time, resource availability, labour availability, the cost for the shutdown would escalate because you can imagine if I could do my shutdown any time, it would mean I would make sure my resources are available but everybody in the Chrome industry has to stop at the same time. It means we don't have to share resources between us, and especially some uncle ends up being the highest bidder would then get job*". This quote illustrates that, even when production is halted for maintenance or due to system constraints, smelters continue to incur substantial fixed labour costs, thereby raising the effective cost per ton over the remaining operating periods. **P7** also linked rising labour and maintenance costs directly to economic and input-cost trends, noting that "increasing electrical cost or tariffs increases labour cost, increasing maintenance cost. That was a killer". " And then basically capital to fund all of these increases. This is because companies in the ferrochrome industry switched off during winter, as the electricity tariff in May, June, and July was so high that it would cause them to produce at a loss.

These comments show that labour, maintenance and other fixed or semi-fixed costs have escalated alongside energy and raw-material costs, compounding the financial pressure on smelters. On the labour side, P6 described how continuous labour downsizing has been used both as a cost-containment measure and as a significant operational challenge. P6 noted that "*the biggest challenge has been the continuous downscaling of labour*." The participant further noted the cumulative impact of repeated restructuring processes when they stated that "*Where we are now, this is the third Section 189 process we are going through. That has been the greatest challenge*." These reflections by P6 highlight that attempts to manage labour costs through downscaling and Section 189 processes have significant implications for workforce stability and the capacity to operate and maintain the plant effectively. From a financial and corporate perspective, **P5** illustrated how deteriorating economics have, in some cases, led to drastic workforce restructuring and the closure of ferrochrome smelters.

This indicates that when cost pressures become unsustainable, companies sometimes respond by retrenching large portions of the workforce and adopting a minimal strategy that may reduce immediate labour costs but also raises concerns about long-term asset reliability and organisational resilience.

Taken together, these accounts demonstrate that escalating fixed, labour and maintenance costs are a central part of the economic challenge facing ferrochrome smelters. Even when production is curtailed, smelters remain "*still paying fixed costs like labour*", while increasing maintenance demands on ageing assets and repeated labour downscaling efforts further complicate the balance between cost control, operational performance and long-term sustainability.

4.4.3 Tonnage dilution and loss-making production

A recurring concern raised by participants in the interviews was that, under current cost and price conditions, some smelters are effectively operating at a loss. Participants explained that when global ferrochrome prices fell while all other costs remained high, operations became unprofitable and most furnaces halted production. P2 described this link between market conditions, cost of production, and profitability: Ferrochrome prices depend on demand from China, driven mainly by global stainless steel production, the Rand-Dollar exchange rate, and global oversupply and shortages. P2 highlighted that *"If the global price drops but our cost of production is high, we become unprofitable. Sometimes you produce at a loss*".

Similarly, P3 gave a concrete example of how the relationship between the selling price and cost of production can result in outright losses by indicating that "*it has increased our cost of production significantly. In some cases, the selling price of ferrochrome is lower than the cost of producing* *it. That means we make a loss".* P3 also said that "*If the Rand strengthens, we make less profit because the selling price is in dollars".* These accounts show that, in periods of depressed ferrochrome prices and high input costs, smelters can find themselves "producing at a loss", despite meeting contractual obligations and maintaining production.

Participants also drew attention to the effect of reduced or interrupted production on unit costs through what can be termed "tonnage dilution". When smelters are forced to curtail production, fixed and semi-fixed costs are spread over fewer tons, increasing the variable cost per ton. From a financial perspective, P5 highlighted that instability in the national power system directly contributes to this effect. P5 stated that "*The instability of the national electricity grid administered by Eskom. This has caused blackouts and load shedding. This leads to downtime and forces operations to curtail production. This directly increases variable cost per tonne because you lose dilution effect".* Furthermore, P5 stated that *"the increase in raw material prices delivered to the plant. Raw materials comprise the commodity price and the transport cost. Transport cost increases due to fuel and logistics issues".*

Here, "lose dilution effect" refers to the loss of cost advantages that would normally arise from spreading fixed and semi-fixed costs across higher tonnages. When production is curtailed, either because of electricity constraints or market-driven cutbacks, the cost per tonne rises even if total spend on labour, maintenance and other overheads does not fall proportionally.

Together, these perspectives highlight that current market and operational conditions not only compress margins but can lead to sustained periods of loss-making production. At the same time, production curtailments and instability undermine the "dilution effect", increasing variable cost per tonne. As a result, smelters face a dual challenge: avoiding situations where the selling price falls below the full cost of production and managing the impact of tonnage dilution when they are unable to operate at optimal capacity.

4.4.4 Link to literature

Participants' emphasis on electricity, ore and reductants as dominant cost drivers aligns with the literature, which indicates that ferrochrome production requires costly resources and is also an electricity-intensive commodity industry. This affirms that competitiveness is determined by input-cost dynamics and cost-curve positioning (DTIC, 2020; Dlamini & Von Blottnitz, 2023). The finding that margin pressure becomes acute when ferrochrome prices drop while the cost of production remains high is consistent with industry evidence that South African producers have increasingly faced viability pressure and have shifted between smelting and ore export when conversion margins are negative (Merafe Resources, 2024).

4.5 Energy Crisis, Electricity Tariffs and Supply Instability

4.5.1 Steep tariff escalation and erosion of competitiveness

All participants viewed the South African energy context as central to the long-term sustainability of ferrochrome smelters. They consistently contrasted South Africa's historical position as a low-cost electricity producer with the current reality of very high, rapidly escalating tariffs. From a strategic perspective, P4 reflected on how electricity moved from being a key competitive advantage to a significant liability when he mentioned that "*Thirty to fifty years ago, we had the cheapest electricity and the endowment of minerals. As a result, most steelmaking and ferroalloys operations were concentrated in South Africa*".

P4 went on to emphasise the scale of electricity price increases over time, saying that "*Electricity prices have increased by 800% in 15 years. That puts everyone outside the cost curve and makes us uncompetitive. That is why today we have only 42 furnaces compared to the 110 we used to have,"* and further explained that it has been incremental all the years. "*Electricity increases above inflation, always double-digit for the last 10 years. That is why we are in this situation*". He also gave some insights into the reason for most of the smelters closing in South Africa by indicating that "*Standalone smelters have all fallen over in the past 10–20 years because they cannot survive market cycles"*.

Now, even vertically integrated producers are falling over because electricity prices are too high, and the cyclical balance no longer protects them.

Participants argued that such steep tariff escalation has fundamentally altered South Africa's position on the global ferrochrome cost curve, making local smelters less competitive than producers in countries with lower or more stable electricity prices. P3 clearly captured, from an operational standpoint, that "*High electricity tariffs for smelting. We need competitive electricity prices to compete with other producers and to produce ferrochrome profitably*".

P3 also noted that even long-term contracts do not protect smelters from the impact of rising tariffs when competing with producers in lower-cost jurisdictions by stating that "*if we sell at 90 US cents per pound and produce at 70, we make profit. But if electricity increases and our cost becomes 95, we lose money even though the contract price is still 90".*

From a financial and market perspective, P5 highlighted how electricity pricing feeds directly into international competitiveness, particularly relative to China, that "*China is now able to beneficiate the final product ferrochrome which is used in stainless steel manufacturing. China receives subsidised electricity from their government, almost half of South African tariffs. This gives China* *a massive cost advantage".* P4 quantified this differential explicitly and stated that "*China gets electricity at one-quarter of South Africa's price, four times cheaper. Years ago, it was the opposite. South Africa had the cheapest power in the world*."

These perspectives support participants' contention that tariff escalation has pushed South African smelters up the global cost curve and eroded the competitive advantage that historically underpinned domestic ferrochrome production.

Participants also stressed that the current tariff trajectory and pricing structure make long-term planning and investment decisions extremely difficult. P2 argued that electricity pricing needs fundamental reform if smelters are to remain viable by mentioning that "*we need negotiated electricity pricing for smelters. Electricity is the highest input cost. Without competitive electricity pricing, there is no smelter in the world that can survive*" and also further stated that "*Electricity price reform, negotiate a lower, competitive tariff for smelters".*

From a financial modelling perspective, P5 emphasised the magnitude of the tariff adjustment required to restore competitiveness. P5 mentioned that "*We need a 70% reduction. I can't give the exact figure due to confidentiality, but in a recent company meeting, it was communicated that a 70% tariff reduction is required".*

Together, these accounts show that steep and sustained electricity tariff increases have transformed electricity from a cornerstone of South Africa's historical smelting advantage into a critical vulnerability. Tariffs that have risen far above inflation, combined with much cheaper power in competitor countries, have undermined the global competitiveness of South African smelters and introduced significant uncertainty into long-term planning and investment decisions.

4.5.2 Load shedding, load curtailment and furnace instability

Beyond price, the reliability of electricity supply was identified as a critical challenge. Participants described how load shedding and load curtailment disrupt furnace stability, lengthen recovery times and reduce effective capacity. P5 stated that "*The instability of the national electricity grid administered by Eskom. This has caused blackouts and load shedding. This leads to downtime and forces operations to curtail production".* P2 states that "*The energy crisis pushed many smelters to shut down or suspend operations.*

Load curtailment means we have to reduce megawatts. When we reduce megawatts:

- *The furnace cools down*
- *Metallurgical reactions slow down*

- *Tapping becomes difficult*
- *Silicon levels can change*
- *Dust levels increase*
- *Gas system gets unstable "*

From a process-control perspective, P2 explained how electricity instability and load shedding affect furnace behaviour and production:

"*Electricity instability has made it difficult to run a stable furnace. Furnaces need constant power input. If power drops or fluctuates, the furnace becomes unstable.*

Load shedding also caused major issues:

- *Crust on the furnace forms*
- *Metallurgical instability*
- *Electrode breakages*
- *Longer tap cycles*
- *Lower production*
- *Higher specific energy consumption*
- *Increased cost of production*"

Further noting that "*You cannot 'pause' a furnace like switching off a computer. It takes hours or days to recover from a single curtailment request. If load curtailment happens often, like every day, the furnace becomes unstable for the entire week.*

P6 reiterates this statement by stating that "*Load curtailment definitely affects production. If we reduce load, we reduce megawatts. If a furnace runs at 54 MW and suddenly we must run at half of that, it affects stability of electrodes, tapping cycles, the whole metallurgy. It's not like switching off a light and switching it back on".*

P3 emphasised that "*Load shedding affected furnace stability. During load-curtailment periods on the furnaces, we cannot maximise power input. That results in lower volumes of ferrochrome produced. It also impacts furnace stability and increases cost of production".*

P2 further emphasised that furnaces cannot simply be switched off and on without consequences, and that repeated curtailment requests keep the furnace in a permanently unstable state: "You cannot 'pause' a furnace like switching off a computer. It takes hours or days to recover from a single curtailment request.

From an operational management perspective, P6 linked load shedding and electricity constraints directly to the deterioration of the industry and the inability to operate all installed capacity. P6 stated that *"Smelting in South Africa is the highest consumer of electricity. If all smelters were running, load shedding would not be avoidable. Some smelters are offline now because electricity costs are high, making it seem like everything is fine. But if all smelters came online, we would be back to load shedding".* All the other participants have echoed this narrative.

P7 described how Eskom's challenges and inconsistent energy supply create bottlenecks and unplanned downtime, underscoring the sector's dependence on reliable power. They stated that "*With all the challenges that Eskom has had, them not being able to give us consistent power supply, this obviously affects our throughput and the amount of chrome we can produce. They become a massive bottleneck because we are solely reliant on energy".* At the same time, P1 expressed concern that the apparent easing of load shedding at the national level may reflect reduced significant industrial demand rather than a genuine resolution of the energy crisis.

Taken together, these accounts show that frequent load shedding and load curtailment undermine furnace stability, increase specific energy consumption, damage equipment and reduce effective capacity. They also suggest that the recent reduction in visible national load shedding may be partly attributable to the shutdown or curtailment of smelter capacity; if smelters were to return to full operation without substantial improvements in generation and grid stability, participants fear that load shedding "would not be avoidable" and would again threaten both operational performance and long-term competitiveness.

4.5.3 Negotiated Pricing Agreements (NPA) and shutdown planning

Some participants noted that the introduction of Negotiated Pricing Agreements (NPAs) between large users and Eskom has changed how smelters plan their operations. Before NPAs, winter tariff structures made it prohibitively expensive to run furnaces during peak months, leading to long, synchronised shutdowns across the industry. P7 described how winter tariffs historically drove shutdown decisions: "*In winter, our electricity cost would almost double. So in June, July, August, we would have to take plants for maintenance. Even if we didn't have maintenance, we had to stop because of the electricity cost.*"

Because these shutdowns were driven by tariff seasonality rather than purely technical needs, they created intense competition for limited shutdown resources:

"*Because the whole chrome industry does maintenance at the same time, resource availability, labour availability, and shutdown costs escalate. We don't choose our shutdown period, we are forced into it*".

He further emphasised the fixed-cost implications of this pattern:

"For three out of the twelve months, we are not operational but still paying fixed costs like labour. So that is a massive impact."

Under the subsequent NPA framework, pricing became more predictable and was explicitly linked to load-curtailment commitments. P4 explained how load curtailment is embedded in the NPA structure:

"Load curtailment is part of the Negotiated Pricing Agreement (NPA) that started in 2022. Eskom gave a slight tariff reduction with the agreement that smelters would reduce load when the country is under strain."

He also outlined how this works in practice during peak hours:

"*Peak hours are 6–8 am and 6–8 pm. During these five hours, Eskom may request smelters to pull back. After that, smelters can increase again. Load curtailment enables the country to keep lights on but affects smelters' ability to run consistently*."

From an engineering and planning standpoint, P7 described the benefits of the NPA in terms of shutdown duration and planning:

"*The NPA agreement helped the industry because it gave us fixed electricity cost. It meant shorter shutdowns, better planning, and the ability to run longer before stopping*."

At the same time, he pointed out that these shorter shutdowns also constrain the window available for improvement projects:

"*Shorter shutdown periods due to NPA, less time to implement improvements*."

From an operational perspective, P1 noted that the NPA had been an important collaborative effort with Eskom, but also that it was not permanent:

"*The NPA (Negotiated Pricing Agreement) was a collaborative effort with Eskom, but that has also come to an end."*

Taken together, these perspectives show that NPAs altered shutdown planning by replacing long, tariff-driven winter shutdowns with shorter, more flexible maintenance periods linked to load-curtailment obligations. This has enabled better planning and somewhat improved asset utilisation. However, participants stressed that NPAs provide only partial relief in a still-constrained energy environment: tariffs remain high, load curtailment "affects smelters' ability to run consistently", and in some cases NPA arrangements have already lapsed, leaving underlying structural challenges unresolved.

4.5.4 Link to literature

The findings on tariff escalation and competitiveness erosion align closely with industry performance analysis, which identifies electricity pricing and supply constraints as structural drivers of declining smelter utilisation and market share (DTIC, 2020; NERSA, 2025; Eskom, 2025). Participants' descriptions of curtailment-related furnace instability and higher cost per tonne also align with published evidence that energy intensity and emissions profiles are sensitive to operational instability and efficiency losses in ferrochrome production, reinforcing the cost-curve mechanism described by interviewees (Wei et al., 2023; Dlamini & Von Blottnitz, 2023).

4.6 Raw Materials, Logistics and Infrastructure Constraints

4.6.1 Raw material availability, quality and cost

Participants reported significant challenges in securing reliable supplies of suitable reductants (such as coke and anthracite) and other key raw materials. P1 emphasised that ensuring adequate reductant supply had become a significant constraint for stable smelter performance, noting that *"Our biggest challenge is sufficient reductants",* while P2 and P3 added on this and noted that weather-related disruptions, international supply constraints, and long import lead times can affect availability and cost. In some cases, quality variations in reductants or ore parcels impair furnace performance, necessitating operational adjustments and increasing the risk of unstable conditions.

In addition to availability, participants stressed that the prices and commercial terms of key raw materials have escalated and become more complex, particularly for imported inputs. P3 mentioned that "Some reductants have to be imported because they are not available locally. Imports require at least three months lead time from tender, to awarding, to shipment, to arrival in South Africa".

Looking beyond availability and price, the quality of raw materials emerged as a critical concern, with direct implications for furnace stability and product quality. P1 and P2 noted that both reductant and ore quality have changed over time. P1 stated that "*So raw material quality and consistency have been a major challenge over the last few months and even years*" and further reiterated by P2 by further stating that "On the process side, challenges include, quality of raw materials. Over the years the quality of reductants and ore has changed" and that "*Raw-material variation affects what the plant produces. Poor reductant quality and inconsistent ore affect* *furnace stability, throughput, energy consumption, and ultimately cost of production*". P3 elaborated that "*Raw materials also need to conform to certain specifications. We target specific markets with our ferrochrome, so the quality must be suitable*", while explaining that raw materials must meet specific technical and customer requirements.

Timely delivery and consistent quality were repeatedly linked to furnace performance and throughput, as P3 highlighted that "*bringing raw materials on time is key. We must quantify what is available on site to determine metallurgical practices for the furnaces. Without the right quality and quantity, furnace output is affected*".

The financial impact of these dynamics is further amplified by the escalation of raw material costs over time. P6 provided a clear example of this trend: "five years ago, raw materials were around R* per tonne. Now we are sitting at over R^ per tonne." He stated that "*in the last 12 years, China has been building and ramping up their smelters. Many of them are online and operational now. The demand for raw materials has skyrocketed".*

From a financial and supply-chain perspective, P5 added that, although most raw materials are sourced locally, growing dependence on imported inputs and constrained local suppliers have driven costs higher because "*Majority of raw materials are mined locally, but some have to be imported, such as BF Coke (blast furnace coke) and certain grades of anthracite"*. P5 further explained that imported materials introduce additional layers of cost linked to global market dynamics, stating that "*there has been a shortage of these locally, especially with suppliers like Mittal being unable to meet demand. With Mittal closing, this will worsen. Imported materials drive up costs due to:*

- *exchange rate fluctuations,*
- *import duties,*
- *import taxes,*
- *additional logistics costs. "*

P5 also highlighted how international political and economic events can feed directly into local raw-material costs. P5 said, "*If there are sanctions imposed by the US on a supplier country, we must find alternative suppliers at higher cost. Global events affect the Rand, especially the Rand-Dollar exchange rate. The Rand usually weakens, meaning raw materials cost more".*

In addition, energy costs and market dynamics, logistics costs affect raw-material pricing, P5 mentioned that "*Oil prices affect fuel costs, which affect shipping, harbour transport, and logistics for both raw materials and final product"* and that there is a direct link between there is a direct link between global markets, exchange rates, oil prices, and operational costs.

Collectively, these accounts show that smelters face a complex raw-material challenge: securing sufficient volumes of suitable reductants and ore, managing quality variations that can destabilise furnaces, and absorbing rising costs driven by local supply constraints, global commodity markets, exchange-rate movements, and logistics. P5 highlighted how changes in global commodity prices, freight rates and local port charges further affect the landed cost of raw materials, often in ways that smelters cannot control. The financial impact of these factors is amplified by exchange-rate volatility and the fact that imported materials are typically priced in foreign currency.

4.6.2 Rail decline, road dependence and port bottlenecks

Logistics and infrastructure issues were another prominent subtheme. Participants explained that declining rail performance, together with broader logistical weaknesses, has forced smelters to rely more heavily on road transport for both inbound raw materials and outbound product. At an industry level, P1 framed transport constraints as one of the main structural challenges facing South African ferrochrome:

"Transport constraints, rail infrastructure can't handle the required volumes of ore and exports."

He further noted that, although South Africa has sufficient ore and smelting capacity, the current transport system cannot sustain the required flow, which has resulted in a growing dependence on road haulage:

"*Even now, rail cannot sustain demand, and the roads are full of trucks*."

From an operational and logistics-management perspective, P3 described how the smelter must constantly manage the movement of materials across different modes and regulatory environments. P3 highlighted logistics as a specific challenge, pointing to constraints on road transport and the cost implications when rail infrastructure requires major repair:

"Logistics is another challenge: road transport availability, diesel price fluctuations, and unreliable rail infrastructure. Rail infrastructure is dilapidated and requires repairs, and those repairs increase rail transport cost".

In their view, policy and infrastructure interventions could reduce some of these logistics costs and bottlenecks:

"*If the port agencies improve infrastructure turnaround time, storage, shipment costs, loading logistics will improve, and costs will reduce"*

From a financial perspective, P5 reflected on how the logistical system has deteriorated over time, particularly with respect to rail freight:

"*Over the years, the logistical infrastructure in South Africa has deteriorated significantly. There has been an increase in road transport, which has significantly pushed up costs. This is due to the national rail freight carrier not being able to provide rail transport.*"

Because of this decline in rail reliability and capacity, companies have increasingly turned to road transport, with high cost and safety risk implications:

"Rail is far cheaper. Due to maintenance issues in rail freight, companies now utilise road transport. Road transport drives up costs and is directly linked to changing fuel prices, which fluctuate monthly. There are also increased accidents, as drivers travel long distances without sufficient rest". Further stating that *"Fines and maintenance costs for fleet increase. The cost of tyres goes up, the freight rate goes up. Road transport companies adjust freight rates based on fleet maintenance costs. Rail transport, on the other hand, could be fixed over a period of time".*

P5 further explained that road-based logistics are sensitive to fuel prices and other operating costs:

"*Another factor is transport cost. Diesel price increases affect road transport. Rail infrastructure failing means more trucks on the road, which is more expensive. All of this drives up raw-material cost*."

These logistical pressures extend beyond inland transport to maritime freight and port operations. P5 drew attention to the way global energy and commodity markets feed back into local logistics costs:

"*Oil prices affect fuel costs, which affect shipping, harbour transport, and logistics for both raw materials and final product."*

At the same time, P3 and P4 noted that, while port infrastructure has shown some improvements, it still presents vulnerabilities. P4 remarked that:

"*Transport is still OK. Maputo Harbour improved in capacity and took pressure off Richards Bay and Durban*".

However, he also pointed out that global disruptions can quickly expose constraints in port and shipping capacity:

"*We had challenges during the Russia–Ukraine war when demand for coal surged. Ports became congested, but we still managed to export. We have never closed a year with high stock due to port issues* ."

Collectively, these accounts show that the decline in rail performance, growing dependence on road transport, sensitivity to fuel prices and global freight markets, and periodic port bottlenecks all contribute to higher logistics costs and operational risk. These logistics constraints interact with the broader cost structure and global competition, further eroding the competitiveness and resilience of South African ferrochrome smelters.

4.6.3 Ageing infrastructure and maintenance backlogs

Infrastructural ageing at the plant level was a recurrent concern, particularly for older smelting complexes. Participants described how older furnaces, plants and associated equipment require increasing levels of maintenance and capital expenditure simply to maintain acceptable levels of performance and safety. Reflecting on his experience at an older operation, P7 highlighted the challenges associated with ageing assets:

"I started at Lydenburg. It was actually an old plant, so challenges there were things like old or ageing infrastructure, which came with its own challenges. The fact that you've got older equipment that needs a lot of capital to refurbish to get it to operate at optimum efficiency."

He further emphasised that ageing equipment directly affects availability and reliability:

"availability of equipment, which was a challenge because the equipment was old."

Participants also highlighted the rising cost of maintaining such assets. From an HSECQ and metallurgical perspective, P2 explicitly linked maintenance cost increases to the need to keep older equipment running:

"Then there is maintenance cost. Maintenance has become very expensive because equipment is old. If you do not upgrade, you have to maintain old equipment more often, and that costs money"

In some cases, participants suggested that there were insufficient financial reserves to undertake the level of maintenance and refurbishment required, leading to a pattern of reactive rather than proactive maintenance. As P1 observed:

"From what I've observed, they didn't have reserves to do proper maintenance."

P7 also described how the combination of energy issues and equipment-related problems contributes to unplanned downtime, increased maintenance costs and unstable production:

“This leads to unplanned downtime due to both energy issues and ageing equipment, increased maintenance costs, and creates unstable production”.

These accounts indicate that maintenance teams often operate under resource constraints, forced to prioritise immediate breakdowns and statutory requirements over longer-term renewal and optimisation. Non-critical but important upgrades are therefore frequently deferred, contributing to a maintenance backlog and increasing the likelihood of future failures. Participants linked these infrastructure challenges to both financial constraints and the broader energy and regulatory environment: when margins are thin and capital is scarce, it becomes difficult to justify large reinvestments in ageing assets, even when they are technically necessary to sustain performance, safety, and reliability over the long term.

4.6.4 Link to literature

Participants’ accounts of rising input costs and increased road dependence align with the literature, which identifies logistics bottlenecks as a major system constraint for South African bulk commodity value chains, including ferrochrome, with deteriorating rail performance increasing costs and operating risk (Transnet SOC Ltd., 2025; DTIC, 2020). The observed interaction between input-price volatility (including imported reductants and exchange-rate exposure) and constrained transport capacity supports the broader view that competitiveness is shaped not only by plant-level efficiency but also by upstream and downstream infrastructure performance across the value chain (Merafe Resources, 2024).

4.7 Global Competition, China And Ore Export Dynamics

4.7.1 From global leader to marginal producer

Several participants reflected on the historical shift in South Africa’s position in the global ferrochrome industry. They recalled a period when South Africa dominated global ferrochrome supply, supported by abundant chrome ore and comparatively cheap electricity, and contrasted this with the current context of reduced capacity and heightened vulnerability to domestic cost and policy conditions. From a strategic and historical perspective, P4 highlighted South Africa’s former competitive advantage:

“Thirty to fifty years ago, we had the cheapest electricity and the endowment of minerals. As a result, most steelmaking and ferroalloys operations were concentrated in South Africa.”

"*Yes. On the contrary, South Africa has the best furnace skills in the world"*.

"We still have those skills. It's just unfortunate that we used to have 110 furnaces, and now we have about 42. That reduces the market for skills, but the residual skill in the country is still high more than the market can offer at the moment".

P4 went on to describe how South Africa's share of global ferrochrome production has declined sharply over time:

"South Africa used to produce 5 million tons of the world's 14 million tons of ferrochrome. This year we might not reach 1 million tons"

China has taken 4 million tons of our former capacity. They provide subsidised electricity to industry, and we no longer have competitive electricity. That pushed us out of the market."

He also linked this decline to the contraction of operating smelting capacity within the country:

"*Electricity prices have increased by 800% in 15 years. That puts everyone outside the cost curve and makes us uncompetitive. That is why today we have only 42 furnaces compared to the 110 we used to have.*"

Together, these accounts illustrate a clear transition from South Africa's previous position as a dominant global ferrochrome producer, which was characterised by cheap electricity, strong technical skills and substantial installed capacity, to a more marginal or "swing" role in which output and viability are susceptible to domestic electricity prices, policy decisions and cost structures.

4.7.2 China's strategy and comparative advantages

China was consistently identified as the dominant global producer and consumer of ferrochrome, and participants repeatedly contrasted China's strategic position with South Africa's. They noted that, despite having limited domestic chrome ore reserves, China has built substantial smelting capacity based on imported ore and more favourable operating conditions. From a financial and market perspective, P5 highlighted China's ability to beneficiate chrome using ore sourced from countries like South Africa, and the cost advantage this creates:

China is now able to beneficiate the final product ferrochrome using ore from all over the world, including South Africa, at lower electricity prices than South African tariffs. This gives China a massive cost advantage."

P5 further elaborated on China's broader structural advantages, including labour and infrastructure:

China also has cheap labour, advanced infrastructure in water, electricity, and transport, which South Africa does not have. Skills and quality of infrastructure have been declining in South Africa. This gives China a competitive advantage."

He also linked China's lower environmental and compliance-related costs to its competitive position:

"*Because of this, China's demand for South African ferrochrome has declined somewhat because it's easier to produce ferrochrome in China with lower compliance costs around carbon tax, environmental controls, and health and safety. This further gives them an advantage*."

From a strategic and industry-structure perspective, P4 underlined how China expanded its smelting capacity by capitalising on South Africa's electricity challenges:

"China took advantage of our lack of cheap electricity. They built their own smelters and used all our chrome ore exports to supply their smelters. They built smelters in China and other regions like Inner Mongolia producing ferrochrome and ferromanganese."

He quantified the extent to which China has absorbed South Africa's former share of global ferrochrome production:

China has taken 4 million tonnes of our former capacity. They produce ferrochrome and stainless steel because they have competitive electricity. That pushed us out of the market."

P4 also emphasised the electricity-price differential as a core element of China's comparative advantage:

"China gets electricity at one-quarter of South Africa's price, four times cheaper."

From an operational and long-term competitiveness viewpoint, P7 drew attention to the way China's sustained investment in smelting capacity and reliable throughput has eroded South Africa's edge:

"Long term, it killed our competitive edge. China has constant throughput and can rely on their power supply, whereas we have unreliable throughput, so we cannot reach required throughput."

He also warned that, if current trends continue, China's growth in beneficiation capacity will allow it to exert even more influence over the industry:

“If we don’t do anything, looking at China’s growth in beneficiation, they will end up buying the ore and beneficiating it there. We will be mining, selling to China, and then they will regulate the price.”

The interviews also highlighted how China’s market position is reinforced by secondary chrome supplies and its central role in global demand. P7 noted that:

“*We sell to the Chinese market. If Chinese demand goes down, it affects us a lot. They are the biggest market. When they reduce demand, we are left with a lot of ferrochrome we cannot sell. There are also secondary chrome producers, platinum sector by-products. They also sell to China. So demand gets influenced a lot by China. They regulate the market.*”

Similarly, participants described how China’s ramp-up in smelting capacity and demand for raw materials has reshaped global dynamics. From the perspective of South African participants, these dynamics create a structural disadvantage because local smelters face rising domestic energy and compliance costs while effectively enabling China’s strategy by exporting large volumes of ore. As P2 has stated:

“*We export ore to China, and they beneficiate it. That means we are exporting jobs*.”

P6 stated that:

“For 13 years, China has built up smelters with greater capacity than South Africa, without having any chrome ore. They get all the ore; we export jobs and the mineral”

Taken together, these accounts underscore that China’s strategy of building large smelting capacity on imported ore, benefiting from cheaper, more reliable electricity, lower labour and compliance costs, and strong infrastructure that has enabled it to operate more consistently and profitably, even when global prices are under pressure. In contrast, South African smelters, facing higher and more volatile input costs and constrained by domestic infrastructure and policy conditions, experience this as a profound structural disadvantage and a key factor in their shift from global leader to marginal producer.

4.7.3 Ore exports, internal pricing and resource sovereignty

The role of chrome ore exports in weakening local beneficiation was a strong subtheme across the interviews. Participants expressed concern that South Africa exports large volumes of unbeneficiated ore, which foreign smelters then use to produce ferrochrome and stainless steel, thereby capturing most of the value addition and associated jobs. P1 called explicitly for stronger regulation of ore exports, warning that current patterns undermine domestic beneficiation:

"*Regulate ore exports; exporting 80% of the world's ore to China destroys our beneficiation*"

The same concern was further echoed by P1, that:

"*If we don't regulate ore exports, beneficiation in South Africa is doomed*"

Several participants emphasised that exporting ore instead of beneficiating it domestically effectively amounts to exporting employment opportunities. As P2 put it:

"*We export ore to China, and they beneficiate it. That means we are exporting jobs*"

Another reflection by P2 reinforced this point, linking ore exports directly to the growth of foreign smelters:

"*If I were to make recommendations, the first thing South Africa must do is stop exporting so much ore. We are feeding smelters that are now bigger than ours. We are exporting jobs*."

In contrast, participants argued that retaining ore for local processing would support industrialisation, employment and broader economic linkages. P1 stated that:

"If we keep ore in the country, we can beneficiate, create jobs, and support local communities. Smelting affects more people; one job in smelting affects eight jobs outside. Mining only affects one outside."

"South Africa must retain beneficiation. We cannot continue exporting ore and letting other countries beneficiate it. If we continue like this, we will lose the smelting industry completely."

P7 also linked the survival of smelting directly to the broader mining sector:

"If smelting closes, ore prices will be low. That will kill SA. We need to look at our country and protect beneficiation. If we lose smelting, mining will eventually follow."

Alongside these concerns about raw-ore exports, participants raised internal ore-pricing practices within vertically integrated groups as a key issue. They argued that when smelters are supplied ore at export-parity prices, rather than at the cost of production, the internal cost base becomes uncompetitive relative to simply exporting ore. P2 stated:

"Second, we must change the model for ore pricing. Smelters should not pay export-parity prices for ore from the mines owned by the same group, the way competitors do it"

P3 summarised the current situation as follows:

"Raw material prices are also a challenge because they do not come in cheaper. We use market-related ore pricing, not in-house pricing"

For some, reforming ore-pricing models and export policies were seen as central levers to restore the viability of domestic smelting. P2 combined these recommendations explicitly:

"Electricity price reform, negotiate a lower, competitive tariff for smelters."

"Ore pricing model, smelters should receive ore at cost from group-owned mines."

" Ban or restrict ore exports, keep beneficiation in South Africa."

P6 suggested a more targeted intervention:

"If I were the nation, I would implement a partial ban on chrome-ore exports."

And this was reinforced again by P6 when asked, as part of a three-point turnaround proposal, *"If there are three things you could change in the next 24 months, what would it be?":*

P6 responded;

Negotiated electricity prices with Eskom. Change the model so smelters get ore at the cost of production. Introduce a partial ban on ore exports. Those three would solve our problems. "

Together, these accounts show that participants view chrome ore exports and internal ore-pricing practices as central to questions of resource sovereignty and industrial policy. Exporting large volumes of ore at the expense of local beneficiation is seen as "exporting jobs" and eroding the country's industrial base, while supplying group-owned smelters at export-parity prices is perceived as structurally disadvantaging domestic smelting relative to simple ore exports. Revisiting both national export policies and internal transfer-pricing mechanisms was therefore seen as critical to the long-term sustainability of South Africa's chrome smelting industry.

4.7.4 Link to literature

The narrative of South Africa's shift from global leader to a more marginal producer aligns with sector analyses that link declining domestic smelting to rising local costs and expanding offshore capacity, particularly in China, supported by ore imports and more favourable operating conditions (DTIC, 2020; Merafe Resources, 2024). Participants' emphasis on ore export dynamics and internal transfer pricing is consistent with policy-focused work on the merits and risks of chrome ore export taxation and beneficiation strategy, reinforcing the view that ore-export policy and pricing mechanisms can materially influence local conversion margins and employment outcomes (DMRE, 2007; Lotriet et al., 2023).

4.8 Regulatory, Environmental and HSEQ Pressures

4.8.1 Environmental licences, Chrome-6 and tailings management

Participants acknowledged that environmental regulation and HSEQ standards have become significantly more stringent over the past two decades. Several interviewees explained that environmental legislation now covers multiple domains, including air, water, waste and tailings facilities. P2 said:

"Environmental regulations have become very strict, especially for:

- *Air emissions*
- *Water use*
- *Hazardous waste*
- *Tailings storage facilities (TSFs)*

> *You need permits for everything. Sampling must be done monthly or quarterly. External audits are required. Compliance must be logged and reported. Failure to comply brings penalties or loss of licence to operate. Compliance increases operational cost."*

Chrome-6 (hexavalent chromium) and dust were highlighted as critical environmental and health risks that require ongoing monitoring and control. P1 noted:

"We must monitor dust emissions and Chrome-6. If limits are exceeded, we investigate. But environmental regulations don't hamper operations".

P6 explicitly identified Chrome-6 as the most tightly regulated issue in ferrochrome smelting:

"The highest regulated one is Chrome-6 (hexavalent chromium). It's highly toxic. But it is not a major problem for us because closed furnaces control it well. Reducing components, carbons, anthracite, etc, helps reduce Chrome-6. But those same carbon materials cause carbon emissions, which lead to carbon tax. If we exceed limits, we pay carbon tax. We also have dust particles emitted through stacks if equipment isn't functioning efficiently. So the main issues are Chrome-6, carbon emissions, and dust emissions. "

The P2 summarised the main environmental focus areas as:

“The key issues are:

- *Chrome-6 (hexavalent chromium)*
- *Dust emissions*
- *Carbon emissions*
- *Water contamination”.*

“*Carbon emissions result in carbon-tax liabilities*”

Water-related risks were also emphasised by P7, particularly the need to prevent Chrome-6 contamination of surface and groundwater:

“If Chrome 6 seeps into water streams, you need to spend money to fix that and eliminate it.”

Tailings storage facilities (TSFs) featured prominently in participants’ accounts of environmental and regulatory pressure. They described how TSFs are now designed and operated under much stricter standards, often requiring significant capital investment and new technologies. P4 stated:

“TSFs are now designed with dry stacking technologies using filter presses to recover water and reduce usage.”

From a financial point of view, P5 commented on the cost implications for managing Tailings storage facilities (TSF):

“TSF regulations are very stringent GISTM requirements. Rehabilitation policies are costly.”

“TSF as well. TSF requirements, government requirements, and all legislative requirements on TSFs.”

Participants further noted that TSF-related regulations extend to closure and land rehabilitation obligations. P7 indicated that:

“*TSF side, land rehabilitation. Creating new TSFs requires budgets for rehabilitation. Tailings need land rehab. Regulations require proper closure plans*.”

“piezometers for monitoring, new leak-detection technology, using drones for surveys.”

Licensing and compliance demands were viewed as extensive and resource-intensive. P7 highlighted the cumulative effect of different requirements across water, tailings and air:

“Water use licences. Regulations for tailings, compliance to GISTM standards. Strict environmental compliance in general.”

"Air emissions. To comply, you need air emission licenses, and you must meet minimum emissions allowed into the environment. That affects operations. It means we must inject money to upgrade systems so we produce less air emissions."

"It means we must inject money to upgrade systems so we produce less air emissions."

P6 underlined the overall weight of air and water-related rules on smelter operations:

"Air emissions. Also, water contamination and hazardous-waste handling. Water and hazardous waste are managed well. Air emissions are the biggest regulatory challenge for ferrochrome smelting."

Taken together, these accounts show that environmental licences and HSEQ standards now require intensive monitoring, investment in pollution-control technologies, and adherence to detailed conditions for air, water, waste and TSFs. Chrome-6 control, TSF design and monitoring (including GISTM compliance), land rehabilitation, and air-emission limits all entail substantial capital and operational expenditure, particularly for older facilities that were not originally designed to meet contemporary requirements.

4.8.2 Carbon tax and the cost of decarbonisation

The carbon tax was frequently mentioned as an additional regulatory and cost pressure on an already-constrained industry. At a strategic level, P4 characterised it as a significant challenge for a sector that is both energy- and carbon-intensive:

"The biggest challenge is carbon tax. Under current cost pressure, adding carbon tax makes life extremely difficult for a carbon-intensive industry."

P4 further described how the tax interacts with existing structural constraints, framing it as a second blow on top of high-carbon electricity:

"Government has committed to relaxing enforcement until there is a resolution on electricity or export tax. Carbon tax is a double hit because we already have a large carbon footprint as an industry."

From a production and operations perspective, participants linked the carbon tax directly to emissions from reductant use and to international competitiveness. P3 explained:

"Carbon tax is another major challenge. Smelting relies heavily on reductants, which are carbon sources for reducing chrome oxide. That adds an international competitiveness burden."

Similarly, P2 emphasised the financial consequences of emissions under the current regime:

"Carbon emissions result in carbon-tax liabilities"

At a more aggregate level, P5 summarised carbon tax concisely as an added cost in the value chain:

"Carbon tax adds cost to beneficiation."

Participants also highlighted the difficult trade-offs companies face between significant, long-term decarbonisation investments and simply paying the tax. P6 explained the scale of capital required to eliminate emissions fully and why, under current conditions, many firms opt instead to optimise processes and absorb the tax:

"The biggest risk is losing the licence to operate. Financial implications include carbon tax penalties. It is expensive to eliminate carbon emissions completely; capital would run into billions."

"Given the current climate and challenges we face, it didn't make financial sense to spend billions on eliminating carbon-tax penalties. It made more sense to optimise processes and pay the fee."

Taken together, these accounts show that the carbon tax is experienced as an additional burden, as P4 has stated that "*Carbon tax is a double hit because we already have a large carbon footprint as an industry",* and smelters already pay high electricity tariffs for power generated predominantly from coal, and then face additional taxation on their direct emissions. In an environment of thin margins, capital constraints and multiple competing compliance demands, participants feared that the carbon tax could accelerate the closure or mothballing of smelters rather than enabling realistic decarbonisation pathways, particularly in the absence of strong incentives, supportive energy policy or access to cleaner, competitively priced power.

4.8.3 Health, safety and "over-compliance" concerns

Health and safety were universally treated as non-negotiable priorities. Participants emphasised that chrome smelting and associated mining activities operate in inherently high-risk environments, requiring robust safety systems, procedures and technologies. Participants also highlighted the need for systems, processes and organisational culture that support ongoing compliance and safe operations. P2 emphasised the importance of integrated systems to manage multiple regulatory and risk domains:

*"As an organisation, we need systems to ensure compliance with *CompanyY* standards and legislative standards. Safety of people, equipment, communities, and the environment is critical.*

Our processes contribute to pollution, air, ground, and water, so we need systems to manage that. "

P2 pointed to the cultural and behavioural dimensions of safety, underscoring the importance of leadership, training and communication:

"Culture is also a challenge. You can enforce systems, but people must buy into safe practices. The safety culture is influenced by leadership, teamwork, training, communication, and discipline."

From a regulatory standpoint, participants noted that health and safety regulations now involve multiple layers of oversight and internal control. P5 captured this as:

"Then there's a lot of health and safety compliance, and this is my view twofold. You have comply to government standard regulations. And then you have the company's own internal health and safety policies. This significantly drives up the cost, especially with regard to the business. If I could put it, or to say that the business is continuously in an audit and the costs of these audits, the costs of the additional health and safety measures that are taken."

They also drew attention to the scale of capital investment in health, safety, environmental, and quality projects. As one participant reported:

"Around 33% of our capital budget is spent on those initiatives."

While participants generally accepted these investments as necessary for safe and responsible operation, some expressed concern that the cumulative effect of overlapping regulatory and audit requirements could become excessive. P5 articulated this as a need to balance legitimate compliance with business sustainability:

"I think there's a chance of overkill in terms of health and safety compliance, I think. I don't think we have struck that balance as yet in terms of cost versus benefit. I must admit that health and safety is very important, but there has to be a balance, and sometimes I do not think that some of the initiatives actually directly translate into a benefit person."

Taken together, these accounts show that health and safety are treated as fundamental, with significant investment in technology, systems, training and HSEQ projects. At the same time, participants are aware of a tension between necessary compliance and "*over-compliance*", where an ever-growing share of capital and management attention is directed towards meeting layered requirements. From their perspective, this can risk diverting resources away from productivity-enhancing projects or critical asset renewal, making the balance between safety, compliance and long-term business viability an important aspect of the broader regulatory challenge.

4.8.4 Link to literature

Participants' accounts of increasing compliance demands for air emissions, water licences and tailings management align with the literature on the environmental risk profile of ferrochrome production and the cost implications of managing Chrome6 (Cr(VI)) related wastes and stricter compliance requirements (SAIMM, 2012). The finding that carbon-related policy is experienced as an added cost burden is also consistent with the broader climate-policy trajectory shaping energy-intensive industries. This includes longer-term net-zero transition expectations reflected in the Paris Agreement (UNFCCC, 2016) and emerging trade-related climate measures such as CBAM, which increase the strategic importance of decarbonisation pathways for exporters (European Commission, 2025).

4.9 Technology, automation and skills in the chrome smelting industry

4.9.1 Safety-driven automation and process optimisation

Participants described numerous technological advances aimed at improving safety and process stability in chrome smelting. They emphasised that the industry is fundamentally safety-driven and that a key focus of technological change has been to remove workers from high-risk areas around the furnace. P6 stressed the centrality of safety in the industry and the extent of technological change aimed at removing people from high-risk tasks:

"*Chrome smelting and mining are very safety-driven industries. A lot of progress has been made in technology that removes people from harm's way".*

They went on to describe concrete examples of how manual, mechanised or automated solutions have replaced high-risk activities:

"Examples:

- *Previously, people manually lanced the furnace with hot metal. Now we have auto-lancing machines.*
- *Auto-drilling machines.*
- *Automatic mud-gun systems.*
- *Cleaning the runner: previously done by hand, now machines (TLBs) are used."*

P2 provided further detail on these technologies and how they contribute to both safety and efficiency, and stated that *"these technologies improve safety and efficiency."*

Beyond furnace-front automation, participants also highlighted that there is scope for further automation and digitalisation in laboratories and control rooms. P2 responded by:

"Yes, several:

- *Laboratory automation drastically reduces labour costs and analysis turnaround time.*
- *Real-time process measurements optimise energy usage.*
- *Automated control systems reduce mistakes and improve efficiency.*
- *Reducing downtime through predictive maintenance improves throughput and reduces cost.*
- *AI systems in control rooms help operators make better decisions."*

In terms of process technology, participants noted that South Africa has been involved in significant developments in furnace and process design. P4 stated that:

"*There's been great developments in the industry. There has been development in the DC technology, which started off as an inefficient process, but over the years, it has shown improvement in terms of efficiencies, and there is something that is a very fundamentally South African concept in terms of application in Chrome. And then there have also been improvements in the Premus technology, which has seen higher chromes and lower well, low efficiencies meaning more better efficiencies. So those two technologies have been advanced in South Africa, and that's what I mean by South Africa, have been spearheading the technology side of things. So in terms of technologies employed, those are two flagship technologies, the old Outokumpu technologies becoming outdated, and now we are looking at Smelt Direct, the different technology that's currently under investigation"*

P4 further stated that *"also the Russians are busy with the blast furnace technology on federal alloys, which also promises to be more efficient. So the issue is not efficiency, but efficiency has to be looked at. The issue is the electricity price that's running away that has to be sorted."*

P1 commented on the current efficient technology that is available, which has been in operation at another smelter, saying *"the most efficient technology is the Premus technology"*

P7 added on by touching on automation and process control was also linked to broader efficiency initiatives at the plant level:

"*Process and equipment automation, upgrading lancing machine to auto-lancing, reducing damage. Using high-performance equipment like energy-efficient pumps*."

These innovations have contributed to safer work environments and more stable operations, but participants stressed that they also require new skills and careful change management. P6 described a strategic shift towards reducing manual labour and relying more on automated, data-driven systems:

"A huge focus in downscaling of labour, you know, in the head reduction. So it was also in that area where technology advancements were made. I mean, there are areas, as an example. Where you had an operator who took samples every two hours, you know, take it to the lab and so on and so on. But there have been systems like online moisture analysers, online, particular size distribution analysers, where you place a unit, an instrument that continuously measures. Whatever a human being was doing, the benefits of that are obvious: we have real-time values, and the margin of errors is also reduced greatly. So it's those two areas. Technology was focused on head reduction and also making people safer, removing them from dangerous tasks".

Overall, participants portrayed safety-driven automation, online analysis, advanced process optimisation and newer furnace technologies as central to improving safety, stability and efficiency in South African ferrochrome smelters. At the same time, they acknowledged that realising the full benefits of these technologies depends on developing appropriate digital and automation skills and managing the organisational changes associated with more automated, data-intensive ways of working.

4.9.2 AI, 4IR and digitalisation

Looking ahead, several participants saw significant potential in Fourth Industrial Revolution (4IR) tools and artificial intelligence (AI) for monitoring, control and decision support. P1 emphasised the growing role of AI and machine learning in safety and remote operations:

"AI and machine learning are big. Especially safety-based technologies: cameras, smart lenses, and remote operation systems. These reduce risk to workers."

They also pointed out that AI is already being embedded in safety and compliance systems in South African mining:

"SA mining has also incorporated AI in compliance systems like TMM Level 9. It keeps operators away from harm".

Participants described a range of possible and existing applications of 4IR technologies in smelting, including laboratory automation, remote operation of equipment, predictive maintenance and digital integration of process data. P2 outlined:

"Some examples of technologies that could be implemented:

- *Advanced automation for the laboratory, instead of four people doing analysis, one machine worth R2 million can do everything.*
- *Remote operation of certain equipment removing people from dangerous zones.*
- *Predictive-maintenance technologies sensors, AI systems, and automated diagnostics.*
- *Digitalisation integrating furnace data systems with analytics and machine learning for optimisation.*

But the main barrier is cost."

P2 further elaborated on current and potential uses of automation and digital tools to improve efficiency and decision-making:

"Yes, several:

- *Laboratory automation drastically reduces labour cost and analysis turnaround time.*
- *Real-time process measurements optimise energy usage.*
- *Automated control systems reduce mistakes and improve efficiency.*
- *Reducing downtime through predictive maintenance improves throughput and reduces cost.*
- *AI systems in control rooms help operators make better decisions."*

Applications are not limited to furnaces and control rooms. Participants also discussed the use of digital and remote technologies in other parts of the operation, including tailings and high-risk areas near furnaces. For example, P7 noted:

"TSF side, piezometers for monitoring, new leak-detection technology, using drones for surveys."

P3 pointed specifically to remote automation at the furnace level:

"At the furnaces, high-risk areas can be automated, remote tapping, removing operators from front-end loaders using remote operation. This reduces risk from explosions or furnace run-throughs."

However, participants also recognised that AI and advanced analytics are not a quick fix. They highlighted barriers related to skills, capital and the need to integrate new tools with existing systems and operational realities. P3 mentioned skills constraints:

“Skills gaps in digital and automation also limit implementation. We need engineering skills in automation to move forward.”

Cost and profitability were also seen as significant constraints on the adoption of advanced digital tools by P2, stating that:

“The challenge is that smelters are not making enough money to invest in these systems”

Participants contrasted South Africa’s slow uptake of 4IR technologies with more aggressive investment elsewhere, particularly in China, as P5 pointed out:

China heavily invests in this. They use AI, robotics, IoT, and modern technologies. South Africa is falling behind.”

There was a sense that management needs to embrace higher levels of automation and AI to remain competitive, as P7 emphasised:

*“from the employer. Firstly, I would say we need to go more into automation. 4th generation AI, we need to look at that. We need to let AI work for us to improve; we need to look at *CompanyY* needs to, I would say. R&D department, for the fact that *CompanyY* as a company doesn't have R&D company. For me it's a failure because there's a lot that's happening out there. Looking at all our challenges, energy, for example, ore prices” … “we need to have a department that can help us to improve this current situation for the overall company.”*

Overall, participants saw significant potential in AI, 4IR and digitalisation to enhance safety, optimise energy use, improve asset reliability and support better planning under constrained conditions. At the same time, they cautioned that realising these benefits will require reliable data capture, integration of legacy systems with new platforms, sufficient capital investment and the development of specialised digital and automation skills, with AI tools designed to support rather than replace the professional judgement of engineers and operators.

4.9.3 Barriers: capital, integration and skills

Participants highlighted three main barriers to adopting and scaling new technologies in chrome smelting operations: limited capital, system integration challenges, and skills constraints.

4.9.3.1 Capital constraints

Several participants emphasised that available capital is already heavily committed to mandatory health, safety, environmental and quality projects, leaving less room for new technology investments. P5 explained:

"Looking at the capital that's deployed with regard to head office projects. And I can. Tell you that. Probably looking at about. 33% of your capital budget being spent HSEQ, which is health, safety, environmental and quality projects. And in my view, 33% of your capital budget being spent on those initiatives is significant, and now we're just talking about the capital budget. We're not even talking about the operational budget."

The same participant linked this directly to technology projects, noting that both the macro-economic environment and investor behaviour restrict access to funding:

"I think capital is also the deployment of capital is also one of the barriers to implementation of these technologies. The world economy has been very stagnant over the past couple of years. Right. And. You know that that would also present a challenge. Investors are also a bit more cautious during a period of slow market demand. So finance is not so readily available from investors or, likewise, women. Finance institutions where both parties are actually trying to, you know, balance out their risks in terms of. Not losing capital in the process."

P7 described capital as the "biggest challenge" when trying to implement new technologies:

"Cost of capital. That's the biggest challenge that we've got is capital injection because remember you need capital. It's basically capital-intensive to do most of these upgrades, and then the company has to pay for it in the next 5 to 10 years. So the biggest one I would say is capital takes long approval processes. We get an idea. We want to implement, but the approval processes take forever. The project approval that process, we need to fine tune it because it's a barrier, it's a bottleneck."

Similarly, another participant linked high capital requirements and unstable power supply to delays in adopting available technologies:

"The technological telling, each technological advancement that we can have in the operation or what we have. Within plant x is mainly on the tapping system. However, there is a scope for increasing in terms of technological advancement. However, there are high capital requirements in order to get to those. So now you need more money to inject into those, and also unreliability on the power supply, because you find that with technology, you rely mainly on power, not much on human or on people that you need certain stability to sustain those technological*

advancements that you have, and also the skills gap is something that we have as in South Africa."

The same participant noted that, even where viable automation options exist, capital injection remains the main obstacle:

"Then there are other technologies out there in terms of logistics for loading. There are companies that are already loading without the intervention of people, where everything is highly automated. That's reducing the risk of people being in contact with rolling stock and also within the laboratory. You can go fully automated. Our biggest challenge is to find the capital injection into those."

In another case, P1 described a large cogeneration project where the business case was strong, but the upfront capital requirement and novelty of the technology slowed execution:

"So look. So if it were a normal year, running for us would be normal operation. They would not have been real barriers of not executing the project. So yes, there is. It is a hefty amount of capital that needs to be given to us from head office. However, as I said, the payback on it is very good. It's really, really very good. But the constraints there were, first of all, again, this would have been the first of its time in the southern hemisphere. It would have been the first smelter in South Africa to apply that technology."

4.9.3.2 Skills and workforce-related barriers

Participants also highlighted that the available skills pool is not always aligned with the requirements of newer, more automated technologies. P5 observed:

"And other market barriers to this technology. I would say is. You know, maybe not a so readily available skills pool of employees who can operate this technology, so one would have to invest in training and development of people. Alternatively, if you're also looking at some better technologies such robotics, once again, you'd have to upskill the workforce in a different manner, and that would be to cater for the maintenance of these newer technologies. So, getting them up to speed and becoming conversant with the type of technology."

P5 continued to state that:

"You know, you meet with different generations, different generations within the workforce, right, so you're. Older employees may not be so accepting towards adopting these newer technologies, as they may feel that their jobs are at stake. Whereas. They don't take into account whether these technologies would actually make a good business case. So in some instances, in your workforce also. Plays as a barrier to implementation of these technologies, and I think the only way one

could alleviate something like that is to train people, alleviate their fears and educate them on, you know, what the benefits of the technology are."

At an operational level, this was reinforced in relation to broader labour and skills shortages by P3:

"The other one is skills and labour shortages. Where you need certain skilled people, so retaining certain skills, especially in the services department".

Together, these quotations show that even when promising technologies are available, smelters face intertwined barriers of constrained capital, complex system integration and insufficient or misaligned skills, all of which slow or prevent effective technology adoption and scaling. High capital requirements, uncertain returns, regulatory approvals, investor caution, skills gaps, generational resistance and the complexity of integrating new digital systems with existing operations all act as significant constraints. Addressing these barriers will require not only investment but also focused skills development, organisational change, and strategic prioritisation of digital and automation initiatives.

4.9.4 Link to literature

Participants' focus on safety-driven automation, improved furnace control, and newer technology pathways aligns with the technical literature on the long-run evolution of ferrochrome smelting technologies. This also includes the role of process innovation in improving stability, recoveries, and operational performance (SAIMM/Mintek, 2004; Metix, 2018). The identified barriers, including capital constraints, integration complexity, and skills gaps, are consistent with the industry road map, which highlights capability development and staged technology adoption as necessary conditions for sustained competitiveness, particularly under cost pressure (Letaba & Zulu, 2021).

4.10 Stakeholders, communities and social licence to operate

4.10.1 Doorstep communities, social disruption and corporate social investment

The relationship between smelters and local communities emerged as a central theme in discussions of operational continuity and risk. Participants reported that doorstep communities often view smelters as key sources of employment, business opportunities and social investment, and therefore exert significant influence on operations. As P1 put it:

"They influence our operation because, remember, we need to maintain this relationship between us and them. They look at us as their saviour because we are coming in there for job creation and

then business opportunities. They can affect us if we don't have a good relationship; they can block our roads and then affect our production."

Participants stressed that when expectations are not met or communication breaks down, communities may resort to disruptive actions that directly affect production. P1 warned that unresolved community grievances can result in extended strikes and substantial production losses:

"So we've seen it in areas like Rhovan, where the community strike would last more than a week. You lose millions of production because of your inability to engage with stakeholders."

P2 highlighted similar risks, emphasising how unrest, vandalism and theft can render plants inoperable:

"They can make your plan not operable because of what? Because of the unrest, they are blocking roads, they are vandalising. They are those that are stealing. Because if people are not working, what are they going to do? How are they going to feed their families? So you run a huge risk."

From a financial perspective, community unrest and strikes were described as serious threats to both continuity and cost. P5 explained:

Industries such as the smarting industry play a greater role in the sustenance and development of the local communities. This, at times has impeded the work at operations whereby we get community strikes, roadblocks and so forth. So one has to tell you to take that concern quite seriously because I think it is a significant challenge to navigate, yeah."

P5went on to spell out the direct operational, cost and legal implications when community conflict escalates:

"So basically if there is a community strike, right, your operations can come to a complete standstill. And would. That being said, there can also be physical damage to the assets itself, and then also you know, damage to employees' property and you know. The infringement of one. Towards employees that would result in costs having to be incurred to restore operations to its normal operating capacity. Also, you know, the last time that's, you know, downtime in terms of operations directly translates into an additional cost for the company. And also, there could be a legal liability from the company's perspective when employees come to work. The company has a legal obligation to ensure that all employees and its contractors, or whoever's on site, are safe at all times in terms of the Occupational Health and Safety Act. So these sort of disruptions can directly translate into a higher cost of production."

Others reinforced how rising unemployment and crime intensify community pressure on smelters. P4 noted that smelters are increasingly expected to fill gaps left by the state:

“There are many other stakeholders. We have corporate social investment. Which is important in the communities where we operate, and we have seen it becoming extremely difficult to operate in the country, given the current unemployment rate. So there's a lot of committed community demands that are coming at our doorstep, where they require us to. Start providing services that the government should be providing. They start requiring employment. Which is not unheard of, but we are currently employing people from the local communities, and the communities are finding more unemployment, and they want us to employ more, which is becoming quite difficult, so operating environment from a corporate social investment around the communities where we operate. Although you still spend money in it, we are seeing that the demand is becoming higher and things are becoming a little bit more violent, more militant… But we've also found that even if you are doing work around the community, Building Schools, building crashes, it still doesn't seem to be enough.”

To mitigate these risks and maintain a social licence to operate, smelters invest in corporate social investment (CSI) initiatives and structured engagement with local stakeholders. P5 described how community demands have reshaped corporate budgets:

“Yeah, so the community aspects are alluded to that they can actually disrupt operations, also resulting in an increased cost to corporates, whereby a certain percentage of the budget has to be allocated to Community development initiatives, supplier development initiatives and so forth.”

At the site level, engagement and CSI are institutionalised through regular stakeholder forums and targeted projects. Describing practices at Plant z*, P7 explained:

“Yeah, look for example, as Plant x, we've got monthly and quarterly stakeholder engagements where we would meet with the local chiefs, elected people around the area, and then they would then give us a list of their concerns. We share with them business opportunities. We share with them how the business is doing. Obviously, on the high level, if there are any opportunities, we start locally. To try to get local people we invest in, we get partners to the local employees or the local people. Kids we invest in, in infrastructure by rebuilding the schools or. Building part of their schools annually with the Mandela Day, we also engage, and then we divide different departments. We go out in the local community, we give back by small things painting.”*

Another participant (P2) summarised the reciprocity expected in these relationships, while also noting that business imperatives cannot be ignored:

“Stakeholders like I've mentioned, in terms of the community output, how does the Community influence your operation, because of you take care of them, they will take care of you, right? But you cannot wait for the community. You still have to make money.”

Taken together, these accounts show that doorstep communities are both vital stakeholders and significant sources of operational risk. Participants emphasised that *communities “can block our roads and then affect our production”*, *“make your plan not to be operatable” through unrest, vandalism and theft, and that “if there is a community strike, right, your operations can come to a complete standstill”* with added safety and legal obligations under the Occupational Health and Safety Act. In response, smelters seek to maintain their social licence through ongoing engagement, local recruitment and CSI initiatives such as *“Building Schools, building class”* and *“rebuilding the schools”.* However, participants also acknowledged that *“even if you are doing work around the community… it still doesn't seem to be Enough”,* highlighting a persistent tension between community expectations and what financially constrained smelters can sustainably deliver.

4.10.2 Labour unions, skills and industrial relations

Labour unions were identified as important stakeholders in negotiations on wages, working conditions and restructuring. Participants reported that unions play a legitimate role in protecting workers’ interests, but that union activity and labour regulations can also complicate efforts to increase productivity or realign staffing in response to changing market conditions. P5 summarised this influence clearly:

“So let's say still text or parameter yeah. So firstly, I would start off with the labour regulations, which I'm pretty sure are hard for companies to comply with. Umm. Especially with unions making you know more demands as the years go by. So that's that's one of the, one of the challenges, challenges…”

P5 further explicitly framed unions as a powerful stakeholder group whose actions can disrupt operations if relationships are not managed carefully:

“The other stakeholders that I say influenced operations are the unions. They play a massive role due to the organised labour, and again, if one does not maintain a good relationship with these parties, it can easily result in disruption of the operations.”

Beyond the unions themselves, participants highlighted that the broader labour-law environment constrains how flexibly smelters can manage staffing and costs. As P3 noted:

"and then the labour laws in the country. They affect the flexibility of the company operating at its maximum. Because if you look at our competitors, they don't have such strict labour laws that they, the not, how do I say, seeing an impact, much impact on the fixed cost…"

Organised labour demands were also seen as feeding into higher input costs through their effect on upstream commodity pricing. A P5 explained how wage demands in mining flow through into smelter input costs:

"Yeah, your general increase in the commodity prices itself. Driven by increased labour demands from the unions, this has resulted in an increase in the commodity price of the raw materials that come through. Unions are demanding. A higher pay for their workers and that cost then affects the cost of raw materials. There are. Supplied to the smelter…"

In addition, basic labour costs were described as increasing automatically over time due to statutory requirements, further tightening margins as stated by P7:

"And then labour minimum basic labour cost or the government regulates the basic labour cost. So say an employee, you have to pay the minimum amount, so that increases due to inflation."

These cost and regulatory dynamics sit alongside the direct impact of restructuring on the workforce. Participants described how sustained economic pressure has driven repeated headcount reductions, with significant consequences for industrial relations and morale. From an operational perspective, P6 reflected:

"Ok, I think the biggest challenges that, that we've experienced or that I personally have experienced with the rigging of the plant is the continuous downscaling of our labour."

P6 went on to describe the cumulative impact of multiple retrenchment rounds:

"So actually, I'll make reference from the year 2016 because that's when I moved into a management position, and it has been a great challenge for us. With the pressures to reach the cost forecast, if I can go with that, we've had to continuously downscale."

Currently, where we are, this would be the third section 189 process that we're going through. So that has been the greatest challenge. And then with that as well, the reduced shutdown periods."

"Over the years, it has gone shorter and shorter and shorter, and all of this is to stay competitive with, with, with other industries. When it comes to the cost of production. So, with the reduced shutdown, it is obvious to try to increase the annual production to dilute the cost. And bring down the cost of production."

Taken together, these accounts suggest that while unions are recognised as legitimate representatives of workers, their wage and employment demands, combined with stringent labour regulations and repeated restructuring (including multiple Section 189 processes), place additional strain on labour relations, productivity and cost structures. At the same time, participants implied that constructive engagement, transparent communication, and early involvement of unions remain essential when contemplating operational changes that may affect jobs, to maintain industrial relations stability in a challenging economic environment.

4.10.3 Government, regulators and industry associations

Participants consistently highlighted government, regulators and industry associations as powerful external stakeholders shaping the operating context for ferrochrome smelters. From a compliance perspective, P2 described how both industry bodies and government influence day-to-day operations through standards, monitoring and shared learning:

"Yes. So in terms of the industry association, remember we are affiliated to ICDA and FAPA with others producers. association and so like those ones, the influence is because of the learnings that are being shared, they're good practices that can be implemented as well. So the industrial association, that's how they influence and the community as well. And the government is a monitoring body that monitors our compliance."

Beyond high-level monitoring, regulatory requirements translate into detailed measurement and management obligations at the plant level. P2 explained how environmental and occupational "stressors" become additional tasks and costs:

As well as that, we see a lot of people now opting for a green paste that does not emit hydrocarbons, which is not good for the health of the employees. So those are other things that the government would require you to do. Monitor, take samples, have management plans if you have those stressors, or what do you call it? Those. Yes, they're called stressors, so they will need you to monitor them at a certain frequency. So that ends in a course that adds… But if you've implemented the green paste, then you don't have all of those things because a tab-based paste has its own environmental issues, and it's all health issues.

P6 emphasised that environmental regulation, and especially carbon-tax policy, is now a central element of government influence on the industry:

"So that's the ones that we have in terms of regulatory government, regulations and the carbon tax, which we also penalised for it."

He warned that non-compliance carries not only financial penalties but also existential risks to the smelter's right to operate:

"So. Is the risk of not complying with these regulations losing their licence to operate? I think in addition to the financial implications that I mentioned, especially with regards to the carbon tax, the other one is our licence being rebuked or revoked, so yeah."

From a general-management perspective, P4 linked tightening environmental rules and the carbon tax directly to cost competitiveness and industry viability:

"Sure. I think it's the one. The one aspect is that under these tight cost constraints, market constraints, the government has also tightened their rules in terms of the environment, for instance, now we. Have to pay a carbon tax on top of being under cost pressure, and that even makes life more difficult for an already struggling industry, and the government has responded quite well in terms of that. They have committed to a relaxation of those enforcement measures, so they have actually committed that they will Gazette a reprieve of some sort to sort of postpone or post the carbon tax implementation. Until some sort of resolution on the ferrochrome industry is found in terms of either cheap electricity or export tax, whichever the government prefers, but yes, carbon tax is the one that I can think of. It has impacted us quite severely. As you know, the carbon footprint from a ferrochrome industry. The federal alloys industry is quite carbon-intensive. Our carbon footprint is quite big. So when you impose a carbon tax on an industry that is carbon-intensive, it's sort of a double whammy. It actually makes the cost competitiveness much more difficult."

Industry associations were described as important intermediaries between smelters, mines and the state. P4 outlined how organised structures such as the Minerals Council and the Energy Intensive Users Group (EIUG) facilitate engagement with government and regulators:

"I think the government is one of the biggest stakeholders because at the end of the day, they're the ones granting licences to do your testing, your metals, your exploration, etc. They own the land, but then we've got the Minerals Council to represent the mines more, if I can put it that way. And then we also have industry associations that represent the smelting businesses. Of course, we've got the director of the timetable energy users group, which also works together with them in order to find a solution so that mines, smelters and investors benefit because it is a complex system."

At the same time, P7 (ES) argued that the government must create a more enabling regulatory and investment climate if smelting is to remain viable in South Africa:

“Government. Creating an environment where private sector can flourish. So you look at all their regulations, things like carbon tax, they must make it easier for private sector so that we don't penalise them.”

He linked this directly to long-term industrial strategy and warned of the consequences if government and industry fail to act together:

“So if you give them the opportunity and then we don't work together with the government now and implement your 5/10/15 year plan, we are dead in the water.”

Taken together, these accounts show that government and regulators shape the industry through licensing, environmental and carbon tax rules, while industry associations such as ICMM, FAPA, the Minerals Council and EIUG act as channels for sharing good practices and negotiating sector-wide solutions. Participants stressed that regulatory compliance imposes substantial monitoring and cost burdens, and that mis-calibrated carbon taxes and environmental policies risk a “double whammy” for an already constrained sector. At the same time, they argued that constructive engagement between government, industry associations and companies is essential to safeguard licences to operate, attract investment and design a 5–15-year roadmap that prevents South Africa’s smelting capacity from being *“dead in the water”.*

4.10.4 Link to literature

The findings emphasise that operational continuity in ferrochrome smelting is shaped not only by technical and economic constraints but also by stakeholder dynamics involving communities, organised labour, regulators and industry associations. This aligns with broader South African mining-sector reporting that highlights ESG expectations, stakeholder engagement and governance as central to continuity and investment confidence in resource industries (Minerals Council South Africa, 2023). Participants’ accounts extend this by showing how stakeholder pressures translate into immediate operational risks, such as protests, security incidents and compliance burdens, reinforcing the need to treat social licence as an operational control variable rather than a peripheral CSR activity.

4.11 Strategic responses and recommendations for sustainability and growth

4.11.1 Company-level strategies

At the company level, participants identified several strategic responses to improve sustainability and competitiveness. A recurring message was that survival depends on improving productivity, managing costs, and allocating scarce capital to initiatives with clear impact on output and efficiency. Under severe cost pressure, P7 emphasised how capital spending is increasingly constrained and directed only to essential areas:

“When there's an escalation in costs, capital becomes very hard to get because capital size located to safety, environment and especially safety and environment. It becomes very difficult to get capital for improvements, you know, and also because of the economic challenges in most industries, you know. They end up only, you know, sustaining the ones that are making a profit.”

From an operational perspective, P7 linked cost pressures, ageing assets and reliability, warning that under-investment and stop-start running patterns create instability and higher maintenance costs over time:

“So this leads to then unplanned downtime due to both energy or ageing equipment, increase maintenance cost due to that and then obviously creating a, you know, unstable production or instability in production due to the stop, start, you know, type of operation.”

P7 also described how electricity-cost dynamics have historically shaped shutdown strategies:

“in the past, we used to have yearly shutdowns, which was basically because of high energy cost. So in winter, our cost of electricity would almost double. So in those three months, June, July, August, would then have to take into maintenance. So even if you don't have to do maintenance, we'll have to stop and do our maintenance.”

Deepening the use of automation, advanced process control and data analytics was highlighted as a key operational strategy to increase efficiency and reduce exposure to human error. P6 described the shift from manual sampling to online measurement systems:

“I think the biggest one is we had to reduce labour, so we had to reduce the number of people that we are using in our smelters. Earlier, we used to have people taking samples every two hours manually. Now we have what we call online moisture analysers, online particle size analysers, which continuously measure these two quantities.”

P6 also stressed that these technologies improve both responsiveness and process stability:

“with that, it gives you real-time values as compared to a person going and taking a sample and giving you the result after 4 hours, when it has already caused damage to the process. So that has reduced, you know, that human error and the delay in terms of getting results, which then also improves efficiency in terms of processes. And then we also have on the process control systems, we have what we call automatic process control systems, which can predict the process

behaviour with the historical data, and it can… basically counter any negative or any deviations early on."

Where capital is available, automation projects were seen as having strong business cases. Referring to laboratory automation, P6 observed:

"if you put, let's say, a machine that does analysis in the laboratory, let's say that machine is 2 million rand, and you have four people doing the same job, and if you look at their salaries, you know, this machine pays itself back in a short space of time."

From a broader plant-engineering perspective, P3 emphasised that technology choices should reduce electricity use, improve safety, and lower labour-related risks:

"If you look at our smelter, we are built with a technology that has the capacity to reduce… the input on electricity in our production, so if we can maximise and use them efficiently like your cogeneration plant, which is what we have at… Preheaters, which is what we have also… If we use them to add the best ability and correctly so, then we are able to capture most in all… And use it to reduce the electricity cost, and the material is already pre-reduced or pre-heated before it enters the furnace. That way we use less material and less power… the third thing will be technological advancements. Safety plays a big role in ferrochrome industry, so with technology we are able to reduce……The number of people or neighbours in the operation and use of technology to meet our operational requirements. That way, we are also saving. So, labour costs, as well as the… can I give the neighbour Union impact on the stability of our production?"

Several participants argued that protecting jobs in the long term depends more on improving production and efficiency than on repeatedly cutting headcount. P6 explicitly contrasted labour cuts with productivity gains:

"I always say when it comes to saving jobs, we always, you know, cut heads. But cutting ten people, it's just a drop in the ocean. If you increase production by 50 tons per day, you gain more value than the cost of ten people. And if you look at it again, if you increase production, you might even need more people because you need more eyes on the plant, you know, in terms of making sure that your processes are in control."

Internal pricing and ore-sourcing strategies within vertically integrated groups were also highlighted as critical company-level levers to restore competitiveness. P3 contrasted market-related ore pricing with a more integrated model for their company and called for an ore-tax levy to close the gap with international competitors:

“The raw materials are also a challenge because they're not coming in cheaper, and we are also using market-related. Or pricing not in-house or pricing… So what's important is if the government can help us to impose a tax levy on the competitors out there, that way it helps us to produce… using a slightly cheaper price, this is our competitors who are really at an advantage of using cheaper electricity.”

P5 summarised the main levers he would focus on in an internal strategy to keep smelting viable:

“If we really want to protect smelting. We need to get cheaper electricity. We need to get cheaper and safer raw materials. We need to get technology. That is still safer.”

Together, these accounts show that, at the company level, participants prioritised strategies that directly enhance safety, increase throughput, stabilise assets and leverage automation and process control while also rethinking internal ore-pricing models and capital allocation to favour projects with clear production and cost benefits.

4.11.2 Industry-level collaboration

At the industry level, several participants called for greater collaboration among ferrochrome producers and related mining companies on issues such as energy, logistics and research and development. From the perspective of a smelter engineer, P7 stressed that all stakeholders have a role to play and that collaboration is essential:

“So, for instance, your suppliers are your stakeholders, your people are your stakeholders, your shareholders are your stakeholders, and your customers are your stakeholders. Then realities are, you have other industry stakeholders like customers, you have your contractors, suppliers that are also affected. So collaboration with stakeholders is very important.”

P7 went on to argue that industry actors should work together more deliberately on shared technical and cost challenges:

“I think industry collaboration, we don't collaborate enough. I think we can actually work together in terms of coming up with, you know, research or coming up with implementation of technologies that can benefit the industry as a whole, instead of us, you know, working in silos. We can actually share research. We can combine research and so on and make things easier for the industry as well.”

From a corporate perspective, P6 highlighted that senior leadership is already engaging collectively with government and Eskom through broader industry platforms, especially around negotiated electricity prices and export restrictions:

"the our CEO and our senior managers, executives, we read it in the newspapers. We hear it on radio and TV constantly. Communication and pushing the government, you know, to for negotiated prices, especially on electricity, we hear it as well pushing for a ban in the export of Chrome or."

However, he also pointed out that feedback and progress remain constrained:

"So yes, efforts are being taken to try and address these challenges, feedback is limited, we… It's always that we waiting for feedback, we waiting for feedback, but yes, the proof is there. We can see they are fighting for us. You know, I'm not sure if the government is not coming to the party or there are other issues which we don't see or understand."

Taken together, these accounts show that participants regard industry-level collaboration through forums, associations, joint lobbying, and shared research as a critical lever for addressing common challenges in energy, logistics, safety, and technology. At the same time, they acknowledged that "we don't collaborate enough" and that existing efforts to secure negotiated electricity prices and export reforms are often slowed by limited government responsiveness.

4.11.3 Policy-level interventions

Participants consistently stressed that certain challenges facing South Africa's ferrochrome smelters cannot be solved at plant or company level alone, but require national-level policy interventions. Their recommendations focused on ore-export controls, internal ore-pricing models, electricity pricing, and the design of environmental regulation and incentives.

A strong message was that the unconstrained export of chrome ore undermines local beneficiation and long-term industry sustainability. P1 (PE) argued that electricity price and ore exports are now the two most significant structural issues, and called for export taxes and a national decision to retain more ore for local smelting:

*"Biggest problem we have now, currently or the two biggest things, one is the electricity price, the other one is the export about ores. My view, the export of our ores is the biggest problem there is. We're giving, we supplying, we've got 80% of the w*orld's ore, and we're leaving it away to China like it's nobody's business. But why? There's 23 million tonnes per year deficit in demand of ferrochrome or stainless steel production."

Do not just export, and we also implement the 40% export tax. Do the beneficiation in South Africa, but then you have to meet the world demand.

P1 linked this directly to a broader industrial-policy choice for the country:

“That, to me, is how we will sustain this industry… No, we as a country have to make a holistic decision and say no to export.”

“But we have to have the capacity and the capabilities of producing that demand.”

P6 similarly argued for national-level controls on ore exports combined with an internal ore-pricing model for vertically integrated groups, so that smelters receive ore at cost of production rather than export-parity prices:

“If we can have a ban on our own ore and not a total ban, let us just work with the capacity of the ferrochrome smelting, it's much less.”

The Chrome or that we mine, so some will still be exported. We understand that stakeholders must also make a profit. You know some will still be exported. But I think if there can be a ban. A partial ban on the chrome ore, whatever that's left, it's exported.

P6 further emphasised that such reforms should balance profitability with employment:

“I actually would look at how our competitors are running and then maybe try and develop that model into ours as well, because yes, the aim, the objective is to maximise profits, but also is they've got their responsibility, I believe, to retain jobs as well.”

In the same vein, P3 proposed the introduction of an ore-export levy to give South African smelters a relative advantage on ore costs compared with offshore competitors:

“So what's important is if the government can help us to impose a tax levy on the competitors out there, that way it helps us to produce. Using a slightly cheaper ore price, this is because our competitors who are really at an advantage of using cheaper electricity.”

Policy design around electricity and carbon pricing was also seen as crucial. P4 highlighted how China’s deliberate decision to subsidise electricity for ferro-alloy producers created an “enabling environment” that shifted ferrochrome production away from South Africa:

“China basically took advantage of the lack of electricity in South Africa and the lack of cheap electricity in South Africa. They built beneficiation capacity in China…Now you find South Africa this year. I don't think we will exceed a million tonnes in production, meaning that China has taken up 4 million tonnes out of five.… What really pushed us out of the market is the lack of cheap electricity. And China took a bold government decision to subsidise electricity tariffs towards the industry in China… So they basically pushed us out of the market by creating and enabling an environment of cheap electricity in China.”

P7 (ES) argued that South African policy should similarly focus on creating a supportive environment for private investment, including how carbon tax and environmental regulations are structured:

"Government by creating an environment where private sector can flourish. So you look at all their regulations, things like carbon tax, they must make it easier for private sector so that we don't penalise them.

And then we create an environment where people don't want to come to SA and invest their money… So we need to create an environment where investors out there would want to come to this country and spend their money because they get more out of spending their money here. We need to spend more on renewable energy because we see this energy crisis."

P7 went on to recommend incentive-based approaches that reward compliance and technology upgrading:

"Environmental regulations, you know, like, will it take, I mean, carbon tax, air dust emissions we need. We need to look at that as well. I'm not saying what a company should not look at technology, obviously improving their systems, but we need to make it in such a way. That there are incentives the minute they comply, they get their money back, maybe through tax, so that it creates an environment where I want to comply with these regulations. But I know I'm gonna get back my incentive or the payback will be. That takes part of it, so it will make the company's private sector want to upgrade and comply as much as possible…"

These accounts underline that participants view policy-level interventions as essential to the future of South Africa's chrome smelting industry. They emphasised (i) measures to restrict or tax chrome-ore exports and redirect ore to local beneficiation; (ii) internal ore-pricing models that allow group-owned smelters to receive ore at cost; (iii) reforms to electricity pricing and capacity that parallel the "enabling environment" created in competing jurisdictions; and (iv) environmental and carbon-tax regimes that combine regulatory requirements with tangible incentives for technology upgrading and compliance. Without such interventions, participants warned that domestic smelters will remain structurally disadvantaged relative to competitors with cheaper power, more favourable ore-pricing arrangements and supportive industrial policies.

4.12 Conclusion

This chapter presented and discussed the empirical findings from seven semi-structured interviews with experienced professionals across the South African ferrochrome smelting value chain. Guided by an inductive, grounded-theory-informed thematic analysis, eight interrelated themes were developed that, together, illuminate how operational, economic, regulatory, technological, and socio-political dynamics shape the sustainability and growth potential of South Africa's ferrochrome smelters. The voices of production, engineering, HSECQ, financial, and general management roles, with experience across different chrome smelting companies and plants, converged to depict an industry under multidimensional pressure, yet still actively seeking adaptive pathways.

First, the findings confirmed that cost structure and economic pressures form a foundational constraint on sustainability. Electricity and raw materials dominate production costs, while labour, maintenance and other fixed costs are escalating against a backdrop of volatile ferrochrome prices. Participants described thin or negative margins, "tonnage dilution" at reduced utilisation, and periods of outright loss-making production. These insights empirically substantiate the problem framing in Chapter 1 and align with the literature reviewed in Chapter 2, which positions South African smelters at the high end of the global cost curve.

Second, the country's energy crisis, electricity tariffs, and supply instability emerged as a central, cross-cutting challenge. Steep above-inflation tariff increases for more than a decade have eroded the historic advantage of cheap electricity and pushed many smelters outside the competitive cost curve. That has led to many of the smelters closing down, particularly those companies that did not own their own mines. At the same time, load shedding and load curtailment undermine furnace stability, damage equipment, increase specific energy consumption and reduce effective capacity. Although Negotiated Pricing Agreements (NPAs) have altered shutdown patterns and created some planning benefits, they have not fundamentally resolved the high-cost, low-reliability character of the current electricity regime. Participants' accounts strongly support the assertion that electricity has shifted from a key enabler of ferrochrome competitiveness to a primary vulnerability.

Third, raw materials, logistics and infrastructure constraints compound these energy-related pressures. Smelters face rising reductant and ore costs, quality variability and longer lead times, often linked to global commodity markets, exchange-rate volatility and local supply limitations. Simultaneously, the deterioration of the country's rail freight has driven a structural shift towards more expensive and risk-prone road transportation, while port bottlenecks and global freight dynamics further increase costs, eroding profitability and raising the cost of production. At the plant level, ageing infrastructure and maintenance backlogs reflect capital constraints and a tendency towards reactive rather than proactive maintenance. Capital constraints might result from eroding margins and/or losses over the years, which may be used as a guideline for capital investments. These findings show that sustainability challenges are not limited to electricity, but are embedded in a broader system of input, logistics and infrastructure vulnerabilities.

A fourth set of themes concerned global competition, China and ore export dynamics. Participants narrated South Africa’s trajectory from a dominant ferrochrome producer to a more marginal role in which output is highly sensitive to domestic energy and policy conditions. China, in particular, was identified as the primary competitive benchmark, having built substantial smelting capacity using imported ore, leveraged cheaper, more reliable electricity, and benefited from lower labour and compliance costs. The biggest challenge in the Chinese market is that it is the largest consumer of ferrochrome, which is used in the production of stainless steel, of which China is the largest producer. China, as a country, is both a competitor to South Africa’s Ferrochrome smelters and also their largest consumer. The combination of extensive chrome-ore exports and the lack of discounted internal ore-pricing models was perceived as “exporting jobs” and undermines domestic beneficiation, as it gives South Africa’s Ferrochrome smelting companies little advantage over external competitors, even though South Africa has around 80% of the world's reserves. These perspectives highlight the structural nature of the competitiveness crisis and underscore the importance of ore-export policy and internal pricing models for long-term industry survival.

Fifth, the findings demonstrated that regulatory, environmental and HSEQ pressures have intensified over the past few years. Environmental licences, Chrome-6 control, water-use licences, stringent tailings-storage facility (TSF) requirements and rehabilitation obligations all entail significant capital and operating costs, particularly for older plants. The carbon tax was experienced as a “double whammy” on an already carbon- and energy-intensive sector, adding costs. At the same time, technological decarbonisation pathways remain capital-intensive and dependent on the electricity mix. Health and safety were universally perceived as non-negotiable by the participants, as they have a direct influence on the people who work for their companies and the communities where these companies operate. This has translated into substantial investment in HSEQ projects and technology that removes people from high-risk zones. At the same time, participants cautioned against “over-compliance” that absorbs such a large share of capital and management attention that it undermines investment in productivity-enhancing projects or critical asset renewal. This underscores the delicate balance that must be established between legitimate regulation, environmental responsibility and business viability.

Sixth, the chapter showed that technology, automation and skills occupy an ambivalent position in the industry’s sustainability story. On the one hand, South African smelters have implemented significant safety-driven automation, online analysis, advanced process control and modern process technologies (such as Premus and improved DC furnaces), which enhance safety, stability and efficiency. Participants also identified substantial potential in 4IR tools, AI, predictive maintenance and digital integration across plants and TSFs. On the other hand, capital scarcity, integration complexity, regulatory approvals, investor caution and gaps in digital and automation skills inhibit wider adoption and scaling of these technologies. Thus, technology and skills are simultaneously part of the industry's current strength (especially in process know-how) and a key constraint on its ability to adapt further.

Seventh, the findings highlighted the importance of stakeholders, communities and the social licence to operate. Doorstep communities, labour unions, government departments, regulators and industry associations all exert substantial influence on operational continuity and cost structures. Community expectations regarding employment, procurement and social investment, if not managed carefully, can lead to unrest and operational stoppages, while unions play a crucial role in wage negotiations, industrial relations stability and the management of repeated restructuring processes (including multiple Section 189 exercises) over the past few years. Government and regulators were recognised both as guardians of environmental and safety standards and as critical actors in enabling or constraining, supportive frameworks for beneficiation, energy, carbon and logistics. Industry forums and associations (e.g., the Minerals Council and EIUG) were seen as important platforms for collective engagement, but participants called for deeper collaboration and more decisive policy responses.

Finally, the chapter showed that strategic responses and recommendations already exist at multiple levels, albeit in a fragmented and sometimes under-resourced form. At the company level, participants emphasised focused capital allocation towards projects that clearly improve production, energy efficiency, maintenance reliability, and safety; smarter shutdown and maintenance strategies; and the expanded use of automation and process control where business cases are robust. At the industry level, they advocated stronger collaboration on research and technology development, as well as joint lobbying, particularly in electricity and logistics. They also mentioned that new technology on the market can improve plant efficiency; however, capital constraints from an investment perspective pose a significant challenge. At the policy level, there was conspicuous convergence around a small set of short-term and long-term interventions such as negotiated or reformed electricity tariffs for energy-intensive smelters, revised ore-pricing models within vertically integrated groups, partial bans or levies on chrome-ore exports to support domestic beneficiation, and calibrated carbon-tax enforcement combined with incentives for cleaner technology investment.

In relation to the purpose, aim, and secondary objectives set out in Chapter 1, the analysis in this chapter demonstrates that these have been met at the empirical level. Typical challenges identified in the literature, especially those related to energy, costs, ore exports, logistics, and regulation, were confirmed and further enriched through detailed practitioner accounts. The specific challenges experienced by ferrochrome smelters were explored and described across multiple roles, companies and smelter types, revealing how macro-level pressures translate into day-to-day operational, financial and strategic decisions. In addition, participants' own proposals at the company, industry, and policy levels provide a grounded foundation for actionable recommendations that directly support the third secondary objective.

Overall, the chapter portrays a sector facing a tightly interwoven set of economic, energy, logistical, regulatory, technological, and social constraints, yet one that still possesses significant technical expertise, process knowledge, and adaptive capacity. The evidence suggests that isolated, incremental changes are unlikely to be sufficient. Instead, coherent interventions are required that simultaneously address electricity pricing and reliability, ore-export and internal pricing models, logistics and infrastructure performance, regulatory design (including carbon tax), and investment in technology and skills.

Building on the findings presented here, Chapter 5 will synthesise these insights into an integrated discussion. It will interpret the results in relation to the conceptual framework and literature, articulate their implications for the sustainability and growth potential of South Africa's ferrochrome smelters, and develop a set of practical recommendations for companies, industry bodies and policy-makers.

4.11.4 Link to literature

Participants' responses align with the literature, which suggests that isolated interventions are unlikely to restore competitiveness. Coordinated measures are required across electricity pricing and reliability, beneficiation policy, logistics performance, and operational efficiency improvements (DTIC, 2020; Merafe Resources, 2024). The alignment between practitioner recommendations and policy/industry analyses strengthens the credibility of the proposed strategic direction and supports the argument that sustainability and growth require simultaneous action on the cost structure (energy and inputs), infrastructure bottlenecks, and industry supportive policy conditions.

CHAPTER 5

5 Conclusion and recommendations

5.1 Introduction

This chapter concludes the study by drawing together the insights generated from the literature review (Chapter 2), the methodological framework (Chapter 3) and the empirical findings (Chapter 4). The focus is on interpreting the results' implications for the sustainability and growth potential of South Africa’s ferrochrome smelters and on outlining practical responses at the company, industry, and policy levels.

The motivation for conducting this study was due to the growing vulnerability of South Africa’s ferrochrome smelting industry, despite the country’s substantial chromite endowment and long history as a leading global producer. As highlighted in Chapter 1, the excessive electricity price escalation combined with its supply instability, intensifying global competition (especially from China), rising raw-material and logistics costs, and tightening environmental and carbon tax regulations have placed severe pressure on smelter margins. This has led to the closure of some operations over time and also a repeat restructuring within operations currently running. Against this backdrop, the primary research question guiding the study was:

“What are the key challenges affecting South Africa’s chrome smelters’ sustainability and growth potential?”

To address this question, the study pursued three secondary objectives:

- To investigate typical challenges affecting smelters through a literature study;
- To empirically investigate the specific challenges ferrochrome smelters experience, and
- To recommend actions to address these challenges.

A qualitative, pragmatic case study design was adopted, which used semi-structured interviews with seven experienced professionals occupying production, engineering, HSECQ, senior management and financial roles in South African ferrochrome smelters. Thematic analysis, informed by grounded-theory techniques, was used to identify patterns from data collected from the interviews. Eight overarching themes were developed which were: (1) cost structure and economic pressures; (2) energy crisis, electricity tariffs and supply instability; (3) raw materials, logistics and infrastructure constraints; (4) global competition, China and ore export dynamics; (5) regulatory, environmental and HSEQ pressures; (6) technology, automation and skills; (7)

stakeholders, communities and social licence to operate; and (8) strategic responses and recommendations.

In this concluding chapter, these themes are synthesised and interpreted in relation to the research aims and the wider literature. Section 5.2 briefly summarises the study and reflects on how the findings address the primary research question and the secondary objectives. Section 5.3 discusses the key conclusions, integrating the empirical results with the conceptual and contextual insights from the literature review. Section 5.4 outlines the main contributions of the study for theory, practice and policy. Section 5.5 revisits the study's limitations and delimitations, and Section 5.6 presents recommendations for companies, industry bodies, policy-makers and future research. Section 5.7 closes the chapter and the dissertation with a final reflection on the prospects for sustaining and revitalising South Africa's chrome smelting industry.

5.2 Summary of the study and attainment of objectives

This section provides a concise synthesis of the study and shows how the primary aim and secondary objectives were addressed through the literature review and empirical investigation.

5.2.1 Restatement of the purpose and research question

The purpose of the study was to examine the sustainability challenges faced by South Africa's ferrochrome smelting industry, with a particular focus on understanding the key factors limiting the industry's competitiveness and long-term viability and on proposing strategies to address these challenges.

The central research question guiding the inquiry was:

"What are the key challenges affecting South Africa's chrome smelters' sustainability and growth potential?"

Three secondary objectives were derived from this question:

1. To investigate typical challenges affecting smelters through a literature study.
2. To empirically investigate the specific challenges ferrochrome smelters experience.
3. To recommend actions to address these challenges.

The summary below shows how each objective was met.

5.2.2 Overview of the research design and approach

The approach towards conduction this research was a qualitative, pragmatic case study design was adopted to explore complex, context-dependent challenges that cannot be adequately captured through purely quantitative indicators. Pragmatism allowed the study to focus on "what works" in understanding and responding to the sustainability problem, drawing on the perspectives of those directly involved in smelter operations and decision-making.

The case was bound to South African ferrochrome smelters, their immediate operating environment and the recent period of industry stress and restructuring. Purposive, maximum-variation sampling was used to select seven experienced professionals occupying diverse roles in the value chain: production engineer, HSECQ superintendent/former senior metallurgist, services and production manager, general manager, financial accountant, production superintendent and engineering superintendent. All had more than a decade of industry experience and exposure to multiple plants and furnace types. This supports the credibility and depth of the findings.

The method used for data collection was through conducting semi-structured interviews via Microsoft Teams, using an interview guide that covered operational, economic, regulatory, environmental, technological and stakeholder-related challenges, as well as perceived solutions. Interviews were recorded, transcribed, anonymised and analysed using ATLAS.ti.

The thematic analysis done was informed by grounded-theory techniques (open coding, constant comparison, progressive categorisation), producing eight overarching themes:

- Cost structure and economic pressures.
- Energy crisis, electricity tariffs and supply instability.
- Raw materials, logistics and infrastructure constraints.
- Global competition, China and ore export dynamics.
- Regulatory, environmental and HSEQ pressures.
- Technology, automation and skills.
- Stakeholders, communities and social licence to operate.
- Strategic responses and recommendations.

During data collection, it was observed that by the sixth and seventh interviews, no new substantive categories emerged, indicating thematic saturation for the purposes of this case study.

5.2.3 Objective 1: Typical challenges from the literature

The first secondary objective was to investigate typical challenges faced by smelters through a literature review. Chapter 2 addressed this by reviewing academic, technical and industry sources on South Africa's chrome smelting industry and global ferrochrome markets.

The literature review showed that:

- South Africa retains a large installed ferrochrome smelting capacity, but utilisation has declined due to rising electricity tariffs, load shedding, ageing assets and weak logistics.
- Global competition has intensified, especially from China, India and Kazakhstan, where they have lower energy costs, newer furnace fleets and supportive industrial policy have underpinned capacity growth.
- Electricity has shifted from a historic source of advantage to a structural weakness, with South African industrial tariffs significantly above those of key competitors, and with persistent reliability problems.
- Chrome ore export dynamics, particularly large volumes shipped to China, were identified as undermining domestic beneficiation and contributing to South Africa's loss of market share in ferrochrome.
- Environmental and climate policies, including stricter air, water and waste regulations and the introduction of carbon taxes, have increased compliance costs.
- Logistics bottlenecks (declining rail performance, port congestion, rising road-transport costs) have further eroded smelters' competitiveness.
- Premus, closed SAFs, DC furnaces, cogeneration, technologies and renewable energy integration were identified as potential levers for improved efficiency and decarbonisation, but are often constrained by capital constraints and policy uncertainty

In doing so, the literature review met Objective 1 by identifying a comprehensive set of typical challenge domains in cost, energy, markets, regulation, technology and logistics, which then informed the design of the empirical enquiry.

5.2.4 Objective 2: Empirical investigation of specific challenges

The second secondary objective was to empirically investigate the specific challenges ferrochrome smelters face. Chapter 4 addressed this through a detailed thematic analysis of the interview data.

The findings confirmed and deepened the literature-based picture, showing how macro-level pressures materialise at the plant level:

- Cost structure and economics:
    - Electricity and raw materials costs were consistently identified as having the highest influence over cost of production, creating loss margins during periods of weak market prices. Escalating fixed costs (labour, maintenance, overheads) and “tonnage dilution” during curtailment or shutdowns further increase unit costs.
- Energy crisis and tariffs:
    - Participants described electricity price increases of several hundred per cent over roughly 15 years, pushing smelters “outside the cost curve”. Load shedding and load curtailment disrupt furnace stability, increase specific energy consumption, damage equipment and reduce effective capacity. Although NPAs provided partial relief and planning benefits, the price of electricity was not competitive compared with other countries and also load curtailment or supply reliability issues were not addressed.
- Raw materials, logistics and infrastructure:
    - Smelters continue to face challenges securing sufficient, high-quality reductants and ore at affordable prices, with quality variations and longer lead times. The use of more expensive road transport was adopted due to declining rail freight, while port and global freight dynamics add further costs and risks. Ageing plant infrastructure and maintenance backlogs reflect sustained capital constraints and an indication of investment confidence in the industry.
- Global competition and ore exports:
    - Participants narrated South Africa’s shift from global leader to a more marginal producer. China, using imported South African ore and cheaper electricity, was seen as the main competitive threat. Large-scale ore exports and internal export-parity pricing were perceived as “exporting jobs” and weakening domestic beneficiation.
- Regulatory, environmental and HSEQ pressures:
    - Stricter requirements for air emissions, water use, hazardous waste, TSFs and land rehabilitation have substantially increased compliance costs. The carbon tax was experienced as a “double whammy” for a carbon- and energy-intensive industry. At the same time, health and safety were treated as non-negotiable, with significant capital allocation to HSEQ projects.
- Technology, automation and skills:
    - Safety-driven automation (autolancing, mechanised runner cleaning), advanced furnace control, online analysis, and modern process technologies were already in place in some operations and were viewed positively. However, further adoption

of 4IR tools, AI, and digitalisation is constrained by capital constraints, skills gaps, and system integration complexity.

- Stakeholders and social licence:
    - Local communities, doorstep companies, labour unions, regulators and industry bodies all have strong influences on operations. Communities have expectations regarding jobs and procurement of services from them, which can lead to protests and stoppages. Unions play a central role in wage bargaining and restructuring, while government agencies control licensing and enforcement. Industry associations provide platforms for engagement, especially on energy.
- Strategic responses:
    - Participants already engage in various adaptation strategies, including shutdown optimisation, prioritised capital allocation, process automation, participation in NPAs and industry forums, and articulating clear ideas for further company, industry, and policy-level responses.

Through these themes, Objective 2 was achieved: the study not only confirmed the typical challenges identified in the literature but also provided a rich, multi-perspective account of how these challenges are experienced and managed within South African smelters.

5.2.5 Objective 3: Foundations for recommendations

The third secondary objective was to recommend actions to address the identified challenges. While Chapter 4 already surfaced many participant-driven suggestions, the systematic formulation of recommendations is the focus of later sections in this chapter (particularly Section 5.6).

Nonetheless, the empirical work has clearly laid the foundation for actionable recommendations by:

- Identifying which factors people from the industry consider most decisive (e.g. electricity pricing and reliability; ore-export and internal pricing models; logistics; targeted technology and automation; maintenance strategies; stakeholder engagement).
- Distinguishing between which actions can best addressed at the company level (productivity, maintenance, capital focus, internal pricing, automation), industry level (collaboration on research, lobbying, shared best practice) and policy level (tariff reform, ore-export measures, calibrated carbon tax and incentive structures).

- Highlighting trade-offs and constraints that any recommendations must realistically account for, such as capital scarcity, skills shortages, and the need to balance compliance with business survival.

On this basis, the study is well-positioned to articulate integrated conclusions and practical recommendations, thereby fulfilling the third secondary objective.

5.3 Integrated conclusions

This section draws together the eight themes from Chapter 4 and the literature in Chapter 2 into a set of overarching conclusions about what drives and constrains the sustainability and growth potential of South Africa’s ferrochrome smelters.

5.3.1 Sustainability is fundamentally a cost-and-energy problem.

The first conclusion is that the sustainability challenge of South African ferrochrome smelters is, at its core, a cost-and-energy problem.

Electricity and raw materials dominate production costs, while labour, maintenance and fixed overheads have escalated steadily. Participants described a situation in which:

- Electricity tariffs have increased far above inflation over the past decade.
- Raw materials and logistics costs are rising due to global commodity dynamics, exchange rates, and deteriorating domestic infrastructure.
- Ferrochrome prices are cyclical and often too weak to cover the full cost of production, which has become more prevalent.

Under these conditions, even well-run smelters frequently operate on thin or negative margins. When utilisation falls due to low demand, load curtailment or deliberate shutdowns, “tonnage dilution” means that fixed costs are spread over fewer tons, further increasing unit costs. This confirms and deepens the literature’s depiction of South African smelters as high on the global cost curve and acutely exposed to energy tariffs and utilisation rates.

In short, without structural relief on electricity pricing and a more favourable cost structure, the industry cannot be sustainably competitive in the long run, regardless of operational efficiency improvements.

5.3.2 Electricity has shifted from a competitive advantage to a structural vulnerability.

The second conclusion is that electricity has moved from being South Africa's key competitive advantage to its primary structural vulnerability in ferrochrome.

Historically, cheap and abundant coal-based electricity, combined with rich ore resources, underpinned South Africa's global leadership in ferrochrome production. The empirical evidence shows that this advantage has been reversed:

- Participants reported electricity price increases of several hundred per cent over approximately 15 years.
- Industrial tariffs are now perceived as multiple times higher than those faced by Chinese competitors.
- Load shedding and load curtailment undermine furnace stability, increase specific energy consumption, damage equipment and reduce effective capacity.

Even though NPAs have given some relief from high tariffs and made it easier to predict electricity costs and when the special tariffs end, they haven't changed the big picture: South African smelters have to deal with high, unstable, and unreliable electricity, while their main competitors have lower, more stable energy costs.

This conclusion aligns with the literature, which has stated that South Africa has lost its low-cost electricity status and now struggles to compete with producers that have newer, more efficient furnace fleets and cheaper power. It also explains why some participants described a collapse from around 110 furnaces historically to roughly 40–odd operating units, with many in care and maintenance. Energy prices and availability have become the decisive structural constraint.

5.3.3 Global competition and ore exports have reshaped South Africa's role

The third conclusion is that global competition, mainly from China and South Africa's own ore-export pattern, has fundamentally reshaped the country's position from being a core producer to a marginal or "swing" supplier.

Participants consistently described how:

- China, despite limited ore reserves, has built substantial smelting capacity based on imported South African ore and cheaper electricity.
- Chinese smelters now beneficiate significant volumes of chrome ore into ferrochrome and stainless steel, capturing value that previously accrued in South Africa.

- South Africa exports large volumes of ore and, in some vertically integrated groups, smelters pay export-parity prices for ore from their own mines.

From the participants' perspective, this combination amounts to "exporting jobs" and weakening domestic beneficiation. It structurally favours ore mining and export over local smelting when electricity prices are high, treating ore as if it were going offshore.

The literature similarly records a fall in South Africa's share of global ferrochrome production alongside aggressive capacity growth in China, India and Kazakhstan. The empirical work adds nuance by showing how this is experienced at the plant level: smelters are increasingly forced to curb production or exit the market completely when the conversion margins turn negative, while ore exports continue.

The conclusion is that South Africa's chrome industry now sits in a structurally disadvantageous position as it supplies raw material into a value chain dominated by foreign smelters whose cost base and policy environment are more favourable.

5.3.4 Regulation and carbon policy add real costs, but are not the root cause

A fourth conclusion is that environmental, HSEQ and carbon-related regulations materially increase costs and complexity, but they are not the primary root cause of unsustainability.

Participants described extensive requirements around:

- air emissions (Chrome-6, dust, stack limits),
- water use and contamination,
- hazardous waste management,
- TSF design, monitoring and rehabilitation (including compliance with global standards), and
- carbon tax on direct emissions.

These requirements involve significant capital and operating expenditures, particularly in older plants that were not originally designed to current standards. A large share of capital budgets is now directed to HSEQ projects. Carbon tax, in particular, was experienced as a *"double whammy"* on an industry already dependent on carbon-intensive electricity and reductants.

However, participants were generally clear that these regulations alone do not "kill" the industry. Instead, they exacerbate an already fragile economic and energy context. There was strong support for environmental and safety obligations, as such, with concerns centred more on:

- the cumulative impact of multiple, overlapping requirements;
- delays and uncertainty in permitting processes; and
- the absence of parallel incentives or enabling measures (e.g. for cleaner technology or renewable self-generation).

The conclusion is that regulation and carbon tax policy have also become cost drivers and constraints. Still, they interact with and often amplify deeper structural issues in electricity markets and logistics, rather than being the root cause of the decline.

5.3.5 Technology and skills are conditional strengths constrained by capital

The fifth conclusion is that South Africa retains strong technical capability in ferrochrome smelting, but its ability to leverage technology and skills as a competitive advantage is severely constrained by capital and integration challenges.

On the positive side:

- The country hosts advanced technologies such as Premus and improved DC furnaces.
- Smelters have implemented safety-driven automation (e.g. auto-lancing, mechanised runner cleaning), advanced furnace control, online analysis and some laboratory automation.
- Participants rated South African furnace and process skills very highly, even compared to global peers.

At the same time, the study found that:

- Many plants still rely on ageing equipment with maintenance backlogs.
- Capital constraints limit the adoption of further automation, 4IR tools and renewable/self-generation projects.
- Skills gaps in digital and automation technologies slow down the integration of advanced systems.

Technology and skills thus function as a conditional strength: they offer clear potential to improve efficiency, safety and energy performance, but this potential cannot be fully realised under sustained financial stress and uncertainty.

The conclusion is that technology and human capital are not the primary problem; they are part of the solution, but they require stable policy signals, access to capital, and targeted skills development to make a decisive difference.

5.3.6 Sustainability depends on coordinated action across the company, industry and policy levels.

The final overarching conclusion is that no single lever is sufficient. The sustainability and growth potential of South Africa's ferrochrome smelters depend on coordinated interventions across three levels:

Company level: having disciplined capital allocation, focused maintenance and reliability strategies, internal ore-pricing reforms in integrated groups, further process and safety automation, and better use of data and predictive tools.

Industry level: forging stronger collaboration through associations and forums with a focus on energy, logistics, safety, R&D and benchmarking; joint lobbying for sector-appropriate electricity and ore-export policies; and shared technology initiatives.

Policy level: electricity tariff reform and NPAs for ferrochrome smelters to also include future energy reliability assurances; well-designed ore-export measures and beneficiation incentives; recalibrated carbon-tax enforcement; and frameworks for enabling embedded generation and logistics reform.

The empirical evidence shows that companies alone cannot "save themselves" through efficiency initiatives if tariffs, ore-pricing and logistics remain structurally unfavourable. Equally, policy changes without internal discipline and collaboration will not be enough. Sustainability requires a package of mutually reinforcing actions.

5.4 Contributions of the study

This section outlines how the study contributes to knowledge and practice in industrial sustainability of ferrochrome smelting.

5.4.1 Empirical contribution

Empirically, the study provides a rich, qualitative account of how multiple pressures combine at the plant level in South African ferrochrome smelters. While previous work has quantified capacity, tariffs, production trends and emissions, fewer studies have documented:

- How managers, engineers, HSECQ specialists and financial professionals experience and interpret the sustainability challenge;
- how macro-level factors such as global competition, ore exports and national energy policy translate into specific operational and financial decisions; and

- the lived implications of repeated restructuring, labour downscaling, maintenance deferrals and community pressures.

The findings identified in this study offer a multi-perspective, practice-based view of the industry. This was informed by the participants who provided data through semi-structured interviews. This gives more depth and helps to explain why smelters keep closing or only working part-time, even though there seems to be plenty of capacity and resources.

5.4.2 Conceptual and contextual contribution

Conceptually, the study contributes to understanding industrial sustainability in resource-dependent, energy-intensive sectors under conditions of structural cost and policy disadvantage.

It highlights:

- The interaction between energy systems, global value chains and domestic beneficiation policy;
- The role of ore-export and internal pricing models in mediating who captures value from natural resources.
- The tension between legitimate environmental regulation and business viability when carbon and compliance costs are imposed on top of already uncompetitive energy tariffs, and
- The importance of social licence, communities and unions as part of the sustainability equation, rather than purely technical or economic variables.

In the South African context, the study adds detail to policy debates around ore-export controls, electricity pricing frameworks for energy-intensive users, and the realistic pace and sequencing of decarbonisation in heavy industry.

5.4.3 Methodological and practical contribution

Methodologically, the value of a pragmatic, qualitative case study and grounded-theory-informed thematic analysis for unpacking complex industrial challenges is demonstrated by this study. It shows how relatively small but carefully selected samples of key informants can yield profound insights into system-level problems and potential solutions.

In practice, the study generates actionable, participant-driven recommendations at the company, industry, and policy levels. These recommendations are grounded in the real constraints and trade-offs identified by practitioners and can inform:

- smelter-level strategy and capital planning;
- collective action by industry associations; and
- policy discussions around electricity, beneficiation and carbon.

5.5 Limitations of the study

5.5.1 Overview

As a qualitative case study centred on South Africa's chrome smelting context, this research prioritises depth over breadth. Several limitations should be acknowledged. The study relies on a relatively small number of interviews with seven senior professionals. This is consistent with qualitative, inductive case study guidance that emphasises information-rich cases and saturation over large samples. Still, it nonetheless means that the findings cannot be statistically generalised to the entire industry. The data are based on self-reported perceptions and experiences, which may be influenced by participants' organisational positions, retrospective sense-making and confidentiality constraints. The use of multiple participants from different roles and the triangulation of interviews with documentary sources mitigate but do not eliminate this limitation. All interviews were conducted via Microsoft Teams, and although transcripts were checked and cleaned, automated transcription is imperfect and may have introduced minor errors.

The study is also subject to delimitations that reflect deliberate scope decisions. Geographically, the research is delimited to South Africa and does not include primary data from ferrochrome smelters in other countries. Sectorally, it focuses on ferrochrome smelting operations and does not directly include other parts of the stainless-steel value chain (such as international traders, downstream steelmakers, or end-users) except to the extent participants discuss them. At the stakeholder level, participants were limited to senior technical, engineering, safety, managerial and financial professionals who are directly involved in smelter operations and strategic decision-making; community members, union representatives and government officials were not interviewed. Finally, the temporal focus is restricted to the recent period of industry stress and restructuring, which was ongoing during which the fieldwork was conducted. These delimitations enhance the study's feasibility and ensure alignment with the research questions. Still, they also mean that the findings should be interpreted as context-specific, analytically generalisable insights rather than universally applicable conclusions.

5.5.2 Qualitative, small-sample design

The study is based on seven in-depth interviews with experienced professionals. This is appropriate for a qualitative case study focused on depth and thematic saturation rather than statistical representativeness. However, the findings cannot be generalised statistically to all smelters, companies or stakeholders. They should be understood as providing analytically generalisable insights into key dynamics and patterns. The use of multiple participants with over a decade of experience each across different plants and companies, play different roles and the triangulation of interviews with documentary sources mitigate but do not eliminate this limitation.

5.5.3 Single-country, single-sector focus

The case is bound to South African ferrochrome smelters. While many of the insights may be relevant to other energy-intensive industries (e.g. aluminium, manganese, platinum), the specific configurations of energy tariffs, ore-export patterns and regulatory frameworks are context-dependent. There was no primary data collected from smelters in competing countries, so international comparisons rely on literature and financial reports rather than cross-country interviews.

5.5.4 Organisational and positional perspective

The participants who formed part of this study were senior professionals within the ferrochrome smelter operations. Their perspectives are informed, but they reflect the vantage point of management and technical staff. The study does not include interviews with organised labour representatives, community members, government officials or downstream stainless-steel producers. Their inclusion might further enrich and complicate the picture.

5.5.5 Time-bounded data

Interviews capture perceptions during a specific period of industry stress and restructuring. Energy policy, ore export controls, tariffs, and global markets continue to evolve. Some initiatives (e.g. new policy packages) may change conditions after the fieldwork period. The conclusions remain valid as a snapshot of the period studied but should be revisited as the context shifts.

5.5.6 Lack of quantitative modelling

The study did not include conducting a formal cost-curve modelling, scenario analysis, or quantitative benchmarking across plants. Instead, it relies on qualitative interviews and published information. Future work regarding this topic could complement these findings with a more detailed quantitative assessment of cost structures, tariff scenarios and policy options. The challenge for this modelling might be companies not willing to share data as they may deem it as sensitive and confidential.

These limitations do not negate the value of the findings, but they do shape the scope within which the conclusions and recommendations should be applied.

5.6 Recommendations

Building on participants' views and suggestions, this section presents recommendations at four levels: smelter/company level, industry-level collaboration, policy and regulation, and future research.

5.6.1 Recommendations for smelters and company management

5.6.1.1 Prioritise capital towards high-impact productivity and reliability projects

Given capital constraints, smelters should adopt a disciplined investment portfolio approach. Projects should be prioritised where there is a clear line of sight to:

- increasing throughput or utilisation.
- reducing specific energy consumption.
- improving furnace stability and asset reliability.
- enhancing safety that also supports efficiency (e.g. automation that removes people from high-risk areas and stabilises operations).

Low-impact, “nice-to-have” upgrades should be deferred in favour of projects that materially reduce cost per tonne or protect the licence to operate. There should be a committee within the companies to interrogate and critically assess the level of impact which projects classified under safety will have on the desired goal, and if there are alternative, cheaper options.

5.6.1.2 Protect and modernise maintenance practices.

Cost-cutting via blanket maintenance reductions is likely to be self-defeating. Instead, smelters should:

- strengthen their preventative and predictive maintenance programmes.
- implement proper reliability programs will assist smelters to inject money for maintenance targeted at real areas of concern.
- use shutdown windows strategically, focusing on critical failure points.
- ensure maintenance planning is integrated with production, safety, and energy management planning.
- stable, well-maintained plants are more energy-efficient and safer, and they are better able to withstand periods of load curtailment.

5.6.1.3 Revisit ore-pricing models in integrated groups.

In vertically integrated mining–smelting groups, the company's executives should critically examine whether export-parity ore pricing to internal smelters is strategically appropriate if they still intend to operate smelters in the future when:

- ore exports are profitable, but smelters are loss-making.
- group-level decisions affect national beneficiation and employment.

Where feasible and compliant with competition and tax law, cost-based or discounted internal pricing for smelters could help restore conversion margins, preserve jobs, and maintain technical capabilities that may be difficult to rebuild once lost.

5.6.1.4 Build digital and automation skills.

Smelters should invest in targeted training programmes for engineers, technicians and operators in:

- automation systems and industrial IT.
- data analysis and visualisation.
- basic AI / machine-learning applications for process monitoring.

Partnering with local universities, research institutions and technology suppliers can help bridge skills gaps cost-effectively.

5.6.1.5 Strengthen structured stakeholder engagement.

At the site level, management should maintain or establish structured, transparent engagement platforms with:

- doorstep communities.
- organised labour.
- local and provincial authorities.

Clear communication about constraints, opportunities, procurement possibilities and social-investment priorities can reduce the risk of disruptive protests and build a more stable operating environment.

5.6.2 Recommendations for industry bodies and collective action

5.6.2.1 Intensify joint lobbying on electricity pricing and structure

Industry associations such as FAPA, Minerals Council, and EIUG should coordinate and present a unified position on the following:

- negotiated electricity tariffs or NPAs for strategic ferrochrome smelters.
- tariff structures that better reflect load-curtailment contributions and industrial policy goals.
- transparent criteria for which smelters qualify for special pricing arrangements.
- speaking with one voice will increase the sector’s influence in engagements with Eskom, NERSA and the government.

5.6.2.2 Collaborate on research, benchmarking and technology pilots

The ferrochrome producers should consider:

- shared benchmarking of energy and raw-material efficiency across plants (with appropriate confidentiality clauses).
- co-funded research on process optimisation, decarbonisation pathways, and AI-driven monitoring tools.
- collaborative pilot projects (e.g. cogeneration, embedded renewables, advanced process control) whose lessons can be shared sector-wide.
- joint collaboration in evaluating the feasibility of investing in "Direct Smelting".
- combining key resources reduces individual risk and speeds up learning.

The appetite for Ferrochrome smelting companies to collaborate and further invest capital in an industry that is currently running at a loss will be driven largely by the government’s response to the excessive electricity tariffs through NPA and actions to address energy availability.

5.6.2.3 Coordinate positions on the ore-export policy and beneficiation

Industry bodies, together with the government, should help formulate balanced, evidence-based proposals on:

- chrome ore-export tax or partial bans.
- agreements for this transition to avoid unintended impacts on mining and small producers.
- incentive structures for local beneficiation, including smelting and further downstream processing.

- collaboration between the mining and smelting segments is critical to avoid zero-sum conflicts and align on a shared vision for value addition in South Africa.

Industry bodies must emphasise that if the export of ore continues without any restrictions, the ore prices will continue to increase, low ferrochrome prices will continue to erode margins of local producers, and ultimately, the industry will collapse.

5.6.3 Recommendations for government and regulators

5.6.3.1 Develop a coherent electricity pricing and reliability framework for strategic smelters

Government, in consultation with NERSA, Eskom and industry, should:

- consider long-term NPAs and lower special tariffs for energy-intensive, trade-exposed industries such as ferrochrome, conditional on transparency, performance and employment targets.
- accelerate reforms that permit and facilitate embedded generation and wheeling for smelters, including renewables and cogeneration.
- align these measures with broader national decarbonisation and just-transition objectives.

The goal is not indefinite subsidies, but a transitional framework that prevents premature de-industrialisation while the power system stabilises and decarbonises.

5.6.3.2 Calibrate ore-export controls and beneficiation incentives

Policy on chrome ore exports should strike a balance between:

- protecting and promoting domestic beneficiation.
- avoiding sudden disruptions to mining operations or export earnings.

Options include:

- an ore-export levy whose proceeds partially support beneficiation infrastructure and skills.
- phased partial export restrictions linked to specific domestic capacity targets.
- tax or investment incentives for smelters that expand or modernise local beneficiation capacity.

5.6.3.3 Align carbon-tax enforcement with realistic decarbonisation pathways

Considering the limited energy or constrained situation, the government should:

- keep the carbon tax path clear but let enforcement be more flexible in sectors that are hard to abate and exposed to trade while Eskom's generation capacity mix remain heavily reliant on coal.
- increase tax breaks and allowances for investments in energy efficiency, low-carbon technologies, waste-heat recovery, and renewables.
- ensure that carbon tax revenues are clearly linked to measures that support just transition and industry.

This would help change carbon policy from being mostly seen as a "double whammy" to one that punishes inaction and rewards credible abatement.

5.6.3.4 Streamline environmental permitting and support compliance capacity

Regulators should aim to:

- reduce delays and administrative bottlenecks in issuing and amending water-use licences and air-emission licences and
- consider technical support programmes for older plants needing to upgrade environmental controls.

The objective is high environmental standards with predictable, efficient processes, rather than diluted regulation.

5.6.3.5 Support skills and technology diffusion

The government, SETAs, and universities can all work together to:

- put more emphasis on engineering, metallurgy, automation, and digital systems programs that are relevant to smelters.
- help with apprenticeships and internships in industries that use a lot of energy.
- co-fund applied research bodies or centres that focus on further optimisation of the ferroalloy process, reducing carbon emissions, and using 4IR technologies.

5.6.4 Recommendations for future research

Future studies which will be beneficial to keep South Africa's industries in operation:

- quantify cost-curve dynamics under different tariff, ore-pricing and export-policy scenarios.
- extend the qualitative enquiry to include community members, union representatives, and government officials to capture the full stakeholder spectrum.

- extend this research by using a mixed-method to incorporate quantitative data for more depth.
- investigate which industries will be worst affected if increasing water scarcity and ageing water supply infrastructure is not addressed.
- investigate the feasibility and economics of specific decarbonisation pathways (e.g. cogeneration, renewables, hydrogen-assisted reduction) for different furnace technologies.
- investigate the main challenges which destroyed South Africa's steel industry and if there can be measures to reignite it.
- conduct comparative case studies across energy-intensive sectors (e.g. ferrochrome, manganese, aluminium) to identify cross-cutting and sector-specific issues.
- explore in more detail the organisational change and skills dimension of digitalisation and AI in smelting operations.

5.7 Final reflection

This study set out to understand the key challenges affecting the sustainability and growth potential of South Africa’s ferrochrome smelters and to propose practical responses. By combining a detailed literature review with in-depth interviews from across the smelting value chain, it has been shown that the industry’s difficulties are not the result of a single shock or failure, but of the cumulative interaction of:

- escalating energy and input costs.
- unreliable electricity supply.
- intensifying global competition, especially from China.
- large-scale ore exports and internal pricing practices.
- tightening environmental and carbon constraints.
- ageing infrastructure and capital scarcity.
- complex social and stakeholder demands.

At the same time, the research has highlighted essential assets: substantial installed smelting capacity, deep process and furnace expertise, proven technological routes for greater efficiency, and existing platforms for industry collaboration.

The central message of this chapter is that the future of South Africa’s chrome smelting industry is neither guaranteed nor doomed. It hinges on whether companies, industry bodies and government can move beyond incremental, isolated responses and implement a coherent package of mutually reinforcing interventions, particularly around electricity pricing and reliability, ore-export and internal pricing models, logistics, technology investment and skills.

If such coordinated action is taken, South Africa can still retain a meaningful ferrochrome smelting base, anchor downstream value chains and support jobs and communities linked to this strategic industry. If not, the risk is a continued shift towards raw-ore exports, the erosion of technical capabilities and a more profound loss of industrial competitiveness. If the industry is not assisted to remain sustainable, there is a likelihood that ore prices might be negatively impacted because it will give leverage for other countries to dictate ore prices similar to the current ferrochrome pricing. The biggest impact will be felt by South African citizens as more unemployment will take place due to economic activities.

From this point of view, the sustainability challenge of South African ferrochrome smelters must be seen as a test case for the country's broader ability to manage a just, competitive transition in energy-intensive industries.

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ANNEXURE A: INFORMED CONSENT FORM

NWU®

Ethics informed consent form

MBA STUDY: The challenges affecting South Africa's chrome smelters' sustainability

FIELD OF STUDY: Business Management

NORTH - WEST
RESEARCHER: KL Mabuela

SOUTH-AFRICA

CELL: 0820623102

Email: karabolm@gmail.com

Dear Interviewee

This **Informed Consent Statement** confirms the following information as it relates to the MBA mini dissertation on the investigation of the challenges affecting South Africa's chrome smelters' sustainability.

1. The sole purpose of this study is to obtain information from experts (such as yourself) employed and/or operating in the ferrochrome industry in an attempt to determine the nature of your experience related to the research topic.
2. The procedure to be followed is a qualitative research design, which includes structured, open-ended questions. During a face-to-face, in-depth interview, you will have the opportunity to communicate your views on the relevant topic. Basic background information, such as your name, academic qualifications, and related years of experience, will be asked.
3. The interview will take no longer than 1 hour.
4. If you feel uncomfortable at any point during the interview, you will have the opportunity to express your discomfort or immediately have the option to end your participation.
5. This interview takes place voluntarily.
6. The confidentiality of the interview data is guaranteed. Fictitious names will be utilised when quoting statements in the dissertation.
7. Any confidential information that prohibits the researcher from publishing it in the final dissertation should be communicated during the interview.
8. The interviewee will be given a list of questions to be asked prior to the interview. This is done to ensure a mutual understanding of what will be asked and to avoid confusion during the interview.
9. A summarised copy of the final dissertation will be available to the interviewee upon request.
10. The data gathered from the interview will only be used for research purposes.
11. All personal information collected during this study will be handled in accordance with the Protection of Personal Information Act (POPIA). This is to ensure that your data is processed lawfully, transparently, and securely for research purposes only.

I, (name and surname), hereby declare that I have read and understand the contents of the Informed Consent Statement, and give my full consent to Karabo Mabuela progress with the interview on (date) and use the information communicated by myself to him in his MBA dissertation.

Name and designation	Signature	Date

ANNEXURE B: LETTER REQUESTING PERMISSION

NWU Business School
North-West University
Private Bag x6001
Potchefstroom, 2520
http://commerce.nwu.ac.za/business-school

Date:

GOODWILL PERMISSION:

I herewith wish to request your permission for ___________ to participate in this research, which involves conducting semi structured interviews with employees. Prior to granting permission, please acquaint yourself with the information below.

The details of the project are as follows:

TITLE OF THE PROJECT:

The challenges affecting South Africa's chrome smelters' sustainability

PROJECT SUPERVISOR: Dr JA Jordaan
ADDRESS: 110 Thabo Mbeki Way, Potchefstroom, 2520
CONTACT NUMBER: 071 366 2262

MEMBER OF PROJECT TEAM MBA-Student: Karabo Mabuela
CONTACT NUMBER: 082 062 3102

Ethics Committee of the Faculty of Economic and Management Sciences (EMS-REC)
Chairperson: Prof. Mark Rathbone
Committee administrative coordinator: Ms. Dalene Vorster (018 299 1529)

This study has been approved by the Research Ethics Committee of the Faculty of Economic & Management Sciences of the North-West University and will be conducted according to the ethical guidelines of this committee.

ETHICS APPLICATION NUMBER

To be confirmed

What is this research about?
The purpose of this study is to examine the challenges faced by South Africa's ferrochrome smelting industry in terms of its sustainability. It aims to understand the key factors limiting the industry's competitiveness and long-term viability, including energy constraints, regulatory pressures, and market dynamics, and propose strategies to address these challenges.

Participants
Participants who will be selected will fall into one of the following categories:

- Operations
- Engineering
- Environmental specialists
- Finance

What is expected of the participants?

Participants will be expected to:

- Participate in a 45 – 60 min semi-structured interview with the researcher at a suitable time and private area without interruptions that is convenient for both parties via an online platform or in person. This will be scheduled by the researcher once approved by the NWU ethics committee.
- Respond to the questions in an open and honest manner.
- Inform the supervisor should you feel or experience any form of discomfort or distress during the research process and inform the supervisor if you at times feel the need to terminate your involvement in the research process.

Benefits to the participants

This research study intends to give participants a voice to reveal, explain and reflect on the research topic. No monetary reward shall be made available for participation in the study. They will however be furnished with a two-page communique on the outcomes of the study upon request.

Risks involved for participants

Participation in this study does not create any physical risk to participants as the study does not involve any physical activities or experiments. We, however, have identified certain ethical principles that shall be always maintained to prevent any damage to participants. The focus of these principals will be to protect the dignity of participants and keep all records provided private and confidential.

Confidentiality and protection of identity

Participants will be assigned a unique participant ID. The interview will be recorded and saved with reference to the ID, but data collected shall be regarded as confidential and will not be shared with any 3rd party that is not directly involved in the research process. Personal details of participants and their direct input to the research study shall not be made public. All records of the research shall be kept for a retention period and destroyed by an appropriate means. The findings of the study will be made public; however, they will not contain any raw data that might incriminate certain individuals. All records will be managed in accordance with POPIA guidelines.

Dissemination of findings

The findings of the study will be for academic purposes and will only be utilised to add to the current body of available knowledge.

If you have any further questions or inquiries regarding participation in this research, please contact the researchers for more information.

ANNEXURE C: INTERVIEW QUESTIONNAIRE

Draft Interview Guide

1. Introduction

a. Please introduce yourself and describe your role within the Chrome Smelting Company. Also, expand on your experience in the industry.

2. Operational Challenges

a. What challenges do you experience within your operations or the running of your plants?

b. Please explain how these challenges affect the performance of your smelter.

3. Economic Challenges

a. From your experience, what are the main economic challenges affecting the sustainability and growth of chrome smelters in South Africa?

b. How do fluctuations in global market conditions impact your operations? Please explain your answer.

c. How has the energy crisis in South Africa affected your industry? Expand, please. Follow-up question: What do you think the long-term effects will be?

4. Regulatory Challenges

a. What specific government regulations pose significant challenges to your operations?

5. Environmental Challenges

a. What are the key environmental issues associated with chrome smelting?

b. How do environmental regulations affect your business practices?

6. Technological Challenges

a. What technological advancements have been adopted in the industry?

b. What barriers do you face in implementing new technologies?

7. Stakeholder Perspectives

a. How do different stakeholders (e.g., government, industry associations, business partners) influence your operations?

b. Can you share any collaborative efforts to address industry challenges?

8. Conclusion

a. What suggestions do you have for addressing these challenges? (Referring to all role players: suggestions to management, government, industry, etc.)

b. Is there anything else you would like to add regarding the challenges facing South Africa's chrome smelters?