UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

IDENTIFYING THE EFFECTS OF THE ENERGY TRANSITION ON THE SOUTH AFRICAN COAL MINING SECTOR

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Masters in Engineering in Engineering.

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DECLARATION

I have familiarised myself with the University of the Witwatersrand Student Academic Misconduct Policy (SAMP). I hereby declare that the work I am submitting for assessment is my original work. I affirm that I have not plagiarised, misrepresented, or colluded with any other person or source. I have properly acknowledged, cited, and referenced all the sources that I have used in my work. I also declare that where I have used artificial intelligence (AI) tools it has only been as a means of guidance. The ideas and arguments presented in my work are my original thoughts and interpretations. I acknowledge that any academic misconduct, such as plagiarism or collusion will result in serious consequences. According to the SAMP, these consequences may include a reduced grade, a fail mark, or disciplinary action. The Faculty of Engineering and the University of the Witwatersrand have my consent to investigate any potential academic misconduct in my work. This investigation may include the use of similarity and AI detection software to check the originality of my work. I undertake to abide by the decision of any such investigation.

Signature: S.A. Masindi Date: 19 August 2025

DEDICATION

To my grandfather, who, despite being partially deaf and unable to speak clearly, learned how to write. Thank you for inspiring us to pursue education. Rest well, knowing that we continue to strive for the highest levels of learning.

ABSTRACT

South Africa's coal mining sector is undergoing significant disruption due to the global energy transition towards cleaner and renewable energy sources. As a country historically dependent on coal for both domestic energy production and export revenue, the shift presents complex economic, social, and environmental challenges. This research analysed the effects of this transition through a review of policy documents, economic data, and literature to provide a clear understanding of the sector's trajectory.

Economically, the declining global demand for coal has placed pressure on export volumes, investment, and local employment. Forecasts suggest that South Africa will lose between 25 000 and 35 000 coal mining jobs by 2035, with provinces like Mpumalanga expected to experience the most severe impact. These figures highlight the urgent need for strategic economic diversification and investment in alternative industries to reduce regional dependency on coal. Socially, coal-dependent communities are at risk of economic marginalisation due to job losses and reduced municipal revenues. The study identifies the importance of proactive labour market interventions such as retraining, skills development, and infrastructure investment to support a just transition. Without these, the energy transition can worsen unemployment and deepen social inequality.

Environmental considerations were also analysed, emphasising the imperative for South Africa to align its energy policies with global environmental social and governance goals. The study not only scrutinised the environmental impacts of coal mining but also advocates for a sustainable transition strategy that harmonises economic interests with ecological responsibility. This appeal for alignment acknowledges the link between economic growth and environmental responsibility, encouraging South Africa to take an active part in the worldwide fight against climate change.

The research calls for an active involvement of government, industry stakeholders, and local communities to navigate this transformative period, to have a fair and sustainable transition for all stakeholders involved. This will balance economic objectives with social and environmental responsibility, to have a resilient and sustainable future.

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LIST OF ACRONYMS ABBREVIATIONS

Abbreviation	**Full Form**
CCS	Carbon Capture and Storage
CSP	Concentrated Solar Power
EV	Electric Vehicles
GDP	Gross Domestic Product
ICT	Information Communication Technology
IPP	Independent Power Producers
IRP	Integrated Resource Plan
ITC	Investment Tax Credits
JET	Just Energy Transition
NDP	National Development Plan
NGO	Non-Governmental Organisation
PPA	Power Purchase Agreements
PTC	Production Tax Credits
PV	Solar Photovoltaic
REIPPP	Renewable Energy Independent Power Producer Procurement Programme
RPS	Renewable Portfolio Standards
SARS	South African Revenue Services
TCFD	Task Force on Climate-related Financial Disclosures
UN	United Nations

1. INTRODUCTION

1.1. Overview of Chapter 1

This chapter examines the historical reliance of South Africa on coal as its primary energy source, providing essential context for understanding the environmental, social, and economic implications of this dependency. It sets the stage for analysing the country's energy transition to renewable sources discussed in later chapters. The primary aim of this chapter is to explore the evolution of South Africa's coal-based energy system, its contribution to economic growth, and the associated environmental and societal challenges. The chapter begins by outlining the historical significance of coal in South Africa's energy sector. It then discusses the environmental and societal impacts of this reliance, including pollution and economic vulnerabilities. Finally, the chapter introduces recent policy initiatives aimed at transitioning towards renewable energy. By examining the challenges of coal dependency, this chapter provides a foundation for understanding the urgency and rationale behind South Africa's energy transition, a central theme of this research report. The following section delves into the historical development of South Africa's coal industry, outlining its role in shaping the country's energy landscape.

1.2. Research Background

South Africa's historical dependence on coal as its main energy source has deeply shaped its economic and social development. With vast coal reserves and a well-established coal mining industry, the country has traditionally relied on this fossil fuel for power generation, industrial processes, and domestic use. Coal-fired power stations have historically provided most of the country's electricity, contributing significantly to its economic growth (Minerals Council South Africa, 2022). However, the reliance on coal has come with substantial environmental and societal costs, such as health issues caused by air pollution, displacement of communities for mining operations, loss of biodiversity, and economic dependence on a declining industry that can lead to job insecurity and community instability. The combustion of coal is a major contributor to South Africa's greenhouse gas emissions, significantly impacting its carbon footprint and contributing to global climate change (Burton & Winkler, 2014). This heavy reliance has also resulted in severe air and water pollution, leading to health hazards and environmental degradation, especially in communities surrounding coal mines and power stations (Laisan & Jegede, 2019).

Moreover, this dependence on coal as the primary energy source has raised concerns about energy security. Dependence on a single energy source leaves the country susceptible to price volatility, supply interruptions, and geopolitical uncertainties linked to coal markets (Department of Mineral Resources and Energy, 2024). Recognising the need to diversify its energy sources and reduce its carbon footprint, South Africa has embarked on an ambitious renewable energy programme. This shift is also driven by international pressure and South Africa's commitments under the Paris Agreement. The Renewable Energy Independent Power Producer Procurement (REIPPP) programme has been pivotal in promoting wind, solar photovoltaic (PV), biomass, and hydroelectric power. The programme aims to increase the share of renewable energy in the country's energy mix significantly (Department of Mineral Resources and Energy, 2024).

1.3. Problem Statement

Despite global momentum towards renewable energy adoption and reduced reliance on fossil fuels, South Africa's coal mining sector faces a critical juncture amid the ongoing energy transition. The lack of comprehensive understanding and analysis of the multifaceted impacts that this transition may exert on the sector poses a significant problem. The transition is likely to affect the sector socially, economically, environmentally and the country at large. Without a thorough assessment of the effects, there is a risk of overlooking crucial challenges and opportunities, hindering effective policymaking, jeopardising economic stability, and neglecting the welfare of communities reliant on coal mining. Hence, there is a need for a research to discern the precise nature and scope of the impact of the energy transition on South Africa's coal mining sector. This will facilitate informed decision making and strategic planning for a sustainable and equitable transition to alternative energy sources (International Renewable Energy Agency, 2020).

1.4. Research Aim and Objectives

The aim of the research was to provide an understanding of the energy transition, identify its effects on the South African coal mining sector, and shed light on its global implications. The objectives of the research were to:

1. Investigate existing energy policies and regulatory frameworks in South Africa that are influencing the energy transition, particularly as they relate to the coal mining sector.
2. Evaluate economic impacts of the energy transition on the coal mining sector in South Africa, including effects on employment, gross domestic product (GDP), investment, and regional economies.
3. Analyse environmental impacts associated with the coal sector and evaluate the potential benefits of transitioning away from coal.
4. Explore social impacts of the energy transition on communities and individuals dependent on the coal mining sector, including considerations of job displacement, retraining opportunities, and social welfare.
5. Conduct a comparative analysis with other regions or countries that have undergone similar energy transitions to draw insights and lessons that can be applicable to South Africa's context.
6. Develop future scenarios based on the findings and propose recommendations for policymakers, industry leaders, and relevant stakeholders to manage the transition effectively while mitigating adverse impacts on the coal mining sector and affected communities.

1.5. Research Significance

The significance of identifying the impact of the energy transition on the South African coal mining sector is multifaceted and holds crucial implications for various stakeholders at regional, national, and global levels. Understanding these impacts is essential for the following reasons:

1. Economic diversification and sustainability: South Africa's economy heavily relies on the coal mining sector, contributing significantly to its GDP and employment. By assessing the implications of the energy transition, policymakers and industry leaders can strategise to diversify the economy,

reducing dependence on coal and ensuring long-term sustainability in the face of changing global energy trends.

2. Investment and financial stability: As the world increasingly shifts towards cleaner energy sources, investors and financial institutions are reevaluating their portfolios, reconsidering investments in coal-related projects. Identifying the impact of the energy transition on the coal mining sector is crucial for guiding investment decisions, avoiding potential financial risks, and fostering stable economic growth.
3. Environmental and health implications: Coal mining is associated with significant environmental degradation and health hazards due to emissions and mining practices. Understanding the effects of transitioning away from coal can highlight potential enhancements in air and water quality, public health, and climate change mitigation, ultimately benefiting both local communities and the environment.
4. Policy formulation and regulatory frameworks: Findings from this research can inform the formulation of robust policies and regulatory frameworks. These can encourage a just transition for affected communities and workers, ensuring a smooth shift towards alternative energy sources while addressing socio-economic challenges arising from potential job losses in the coal sector.
5. Global energy dynamics and trade relations: Given South Africa's role as a significant exporter of coal, understanding the energy transition's impact on the coal mining sector is crucial for assessing the country's position in the global energy market. This knowledge can help in negotiating trade agreements, diversifying exports, and positioning the country in emerging global energy dynamics.
6. Social and community impact: The energy transition may have substantial social implications, especially for communities reliant on coal mining for their livelihoods. Identifying the impact allows for proactive measures to support affected communities through retraining programmes, job creation initiatives, and infrastructure development to ensure a just and equitable transition.

Considering the above, the significance of investigating the impact of the energy transition on South Africa's coal mining sector extends far beyond the industry itself. It touches upon economic, environmental, social, and geopolitical aspects, offering an opportunity to steer the country toward sustainable development while managing the challenges associated with shifting away from coal-based energy production.

1.6. Research Scope

This research examined the social, economic, and environmental impacts of coal mining in South Africa, with a focus on Mpumalanga province. As the epicentre of South Africa's coal mining activities, Mpumalanga hosts numerous coal mines and power stations and though it has benefited from employment from this sector over the years, it has also faced significant environmental degradation and social challenges due to its dependence on the coal economy. The province's high density of coal related activities made it an ideal case study, offering insights into the broader implications of coal reliance in the country.

The research examined the impact of coal mining on South Africa's communities, economy, and environment. It considered both the direct effects of coal extraction and the broader socio-economic and environmental challenges affecting the country's long-term sustainability. The study focused on three key areas listed below:

1. Social impacts: The study evaluated the effects of coal mining on local communities, including health risks linked to air and water pollution, and changes in social dynamics. It also investigated employment opportunities provided by the coal mining industry, alongside the potential social instability stemming from the potential sector's decline.
2. Economic impacts: The research examined the economic contributions of coal mining to local and national development, particularly in terms of job creation and regional economic activity. It also considered the vulnerabilities created by economic dependence on coal mining and assessed the potential impacts of transitioning to renewable energy sources.
3. Environmental impacts: The study analysed the environmental consequences of coal mining, including biodiversity loss, air and water pollution, and greenhouse gas emissions. Additionally, it considered the long-term sustainability challenges posed by continued reliance on coal in the wake of the energy transition.

Among the leading coal mining companies in South Africa, Exxaro Resources (Exxaro), Thungela Resources (Thungela), and Seriti Resources (Seriti) were chosen as case studies due to their exclusive focus on coal production. This contrasts with other major producers such as Sasol, African Rainbow Minerals, and Glencore, which operate diversified portfolios across multiple commodities beyond coal. This singular focus allowed for a more precise examination of the direct impacts of coal mining. Furthermore, these companies maintain substantial operations in Mpumalanga, aligning them closely with the geographical focus of the research. Their prominence and specialisation made them ideal case studies for understanding the dynamics of coal mining in the province and the associated social, economic, and environmental implications.

1.7. Summary of Chapter 1 and Report Outline

The report is systematically organised into five chapters. Chapter 1 of this research report introduces the research, focusing on the identification of the impacts of the energy transition on South Africa's coal mining sector. The chapter begins with an overview of the historical and contemporary context of coal mining in South Africa, highlighting its central role in the country's economy and energy infrastructure. It then presents the problem statement, which outlines the challenges the coal mining sector faces due to the global shift towards renewable energy. The research aim is clearly defined, seeking to assess the extent of these impacts on the coal mining industry and explore potential pathways for a just transition in the sector. The significance of the study is discussed, emphasising its potential to inform policy, industry practices, and the broader energy transition in South Africa. The chapter concludes with a detailed research scope, outlining the boundaries of the study, including its focus on social, economic, and environmental impacts, as well as the geographical context. The selection of specific coal mining companies, such as Exxaro, Thungela, and Seriti, is justified, given their exclusive focus on coal mining and significant operations within South Africa's coal industry (Hancox & Götz, 2014). This chapter sets the foundation for the subsequent analysis, framing the research within the context of the evolving energy landscape and the challenges facing the coal sector.

Chapter 2 provides a comprehensive review of existing literature related to the effects of the energy transition on the coal mining industry in South Africa. This review encompasses previous research findings, theoretical frameworks, and empirical studies that offer insights into the broader context of the energy transition and its implications for coal mining. Chapter 3 describes the research methodology employed in the study. It describes the research design, data collection methods, and analytical techniques used to investigate the impacts of the energy transition. This chapter also discusses the rationale behind the chosen methods and address any limitations associated with the research approach.

Chapter 4 presents the findings of the research, including a detailed analysis of the data collected. It interprets the results in relation to the research aim and objectives, highlighting key trends, patterns, and insights into the impact of the energy transition on the coal mining sector. Chapter 5 provides the research conclusions drawn from the research findings and provides actionable recommendations based on the conclusions. It suggests potential strategies for mitigating challenges and capitalising on opportunities within the coal mining sector, aiming to support sustainable development and informed decision making in the context of the ongoing energy transition.

2. LITERATURE REVIEW

2.1. Overview of Chapter 2

This literature review chapter brings together and evaluates current research on how the energy transition is affecting South Africa’s coal mining sector. It offers a detailed look at how policies, new technologies, market shifts, social and economic factors, and environmental issues interact to shape the future of coal in the country. The review also places South Africa’s experience in a global context by comparing it with other countries undergoing similar transitions. Lessons and best practices from these case studies provide useful guidance and strategies for South Africa’s transition from coal.

By critically evaluating the existing literature, this chapter provides a comprehensive understanding of the challenges, opportunities, and implications associated with the energy transition's impact on South Africa's coal mining sector. Ultimately, the chapter provides a knowledge base that can inform policymakers, industry stakeholders, and researchers in charting a sustainable and inclusive path forward for the country's energy transition. The following section discusses the historical overview and importance of coal in Suth Africa.

2.2. Historical Overview and Importance of South Africa's Coal Sector

The coal industry in South Africa finds its genesis in the late 1800s with the discovery of extensive coal deposits in various regions of the country (Davenport, 2013). The development of coal mining gained momentum during this period, spurred by the increasing demand for coal as a primary source of energy for industrial and domestic purposes (Davenport, 2013). South Africa’s coal reserves, particularly in areas like Mpumalanga and Limpopo, facilitated the rapid growth of coal mining operations. This growth aligned with the country's industrialisation, as coal became a fundamental driver of economic development and infrastructure expansion (Hancox & Götz, 2014). The 20th century witnessed a significant expansion of the coal sector in South Africa. The sector's importance surged as it became a critical component of the country's energy mix and a key contributor to the country’s economic prosperity. Coal mining activities expanded, contributing substantially to the country's GDP and export revenues (Davenport, 2013).

The second industrial revolution marked a transformative period in South Africa, characterised by significant advancements in technology, manufacturing, and economic development (Freund, 1984). Coal played a pivotal role in driving this revolution, particularly in powering machinery and stimulating industrial growth across various sectors (Davenport, 2013). The discovery and utilisation of coal reserves during the second industrial revolution were crucial for mining operations and the subsequent growth of the mining industry. Coal-powered steam engines were instrumental in extracting minerals, not just coal itself, contributing to the development of the mining sector (Conor, 2024). Moreover, the availability of coal spurred the construction of railways and facilitated the transportation of goods and resources, supporting the expansion of infrastructure and regional connectivity (Fourie & Herranz-Loncan, 2015).

Coal served as a primary energy source, powering machinery in factories and driving industrial processes (Freund, 1984). From textiles to metalworking, coal-fired steam engines played a central role in manufacturing, enabling mass production and transforming traditional artisanal methods into large-scale industrial processes. The reliance on coal for energy generation and industrial activities led to urbanisation as people moved to areas with burgeoning industries. Cities like Johannesburg and Witbank saw significant growth due to coal mining and related industries (Munnik *et* al., 2010). Gold mines in Johannesburg required coal as an essential energy source to power the machinery used in gold mining operations. This urbanisation fuelled economic growth, created employment opportunities, and attracted labour from rural areas to work in mines and factories (Munnik *et al*., 2010).

The second industrial revolution, fuelled by coal consumption, brought about profound social and economic changes. The rise of factories and industries changed the nature of work, with more people employed in industrial settings rather than traditional agriculture (Freund, 1984). This shift had lasting effects on society, altering lifestyles, social structures, and the division of labour. Technological advancements played a crucial role in shaping the coal industry. Innovations in mining techniques, machinery, and processing methods increased efficiency and productivity, transforming South Africa into a notable global player in the coal market (Baker *et al*., 2014).

2.3. The Role of Coal in South Africa’s Economic Growth

Coal has played a pivotal role in shaping South Africa’s economic landscape, driving much of the country's industrialisation and economic development (Dikgwatlhe, 1998). As one of the world's top producers of coal, South Africa’s vast coal reserves have been integral to energy production and the expansion of various industries. Coal has been the cornerstone of South Africa's energy sector, powering the country’s electricity generation and providing fuel for industrial processes (Minerals Council South Africa, 2022). This reliance on coal has not only fuelled domestic growth but has also positioned South Africa as a key player in the global coal export market. The next subsections discuss some of the roles of coal in South Africa’s economic growth.

2.3.1. Energy production and industrialisation

Coal has been the backbone of South Africa’s energy production, fuelling much of its industrialisation and economic expansion (Ebenhart, 2011). The country’s abundant coal reserves have been crucial to the generation of electricity, with coal-fired power stations accounting for most of the country’s electricity supply (Eskom Holdings SOC Ltd, 2023). This energy supply has supported the growth of critical industries, including manufacturing, mining, and steel production. The development of energy-intensive sectors, particularly in regions such as Mpumalanga, where significant coal reserves are located, has facilitated industrial growth and contributed to job creation. Additionally, coal's role in powering industrial processes, from textiles to metalworking, has been central to South Africa's economic development, enabling mass production and transforming traditional artisanal methods into large-scale industrial processes (Dikgwatlhe, 1998). As South Africa continues to rely heavily on coal, it remains a cornerstone of the country’s industrial landscape.

2.3.2. Economic contribution of the coal sector to South Africa

The coal mining sector has made substantial contributions to South Africa’s GDP. According to Minerals Council South Africa (2023), the whole mining industry contributed 6.2% to the country’s GDP in 2023, of which 2%–3% came from coal mining. Revenue generated from coal mining operations, exports, and related industries has been a key driver of economic growth. South Africa's abundant coal reserves have enabled the country to meet both domestic energy demands and export requirements. Coal exports have been a valuable source of foreign exchange earnings, significantly contributing to the trade balance and strengthening international trade relationships (Minerals Council South Africa, 2023). Figure 1 indicates the percentage contribution per commodity for 2023.

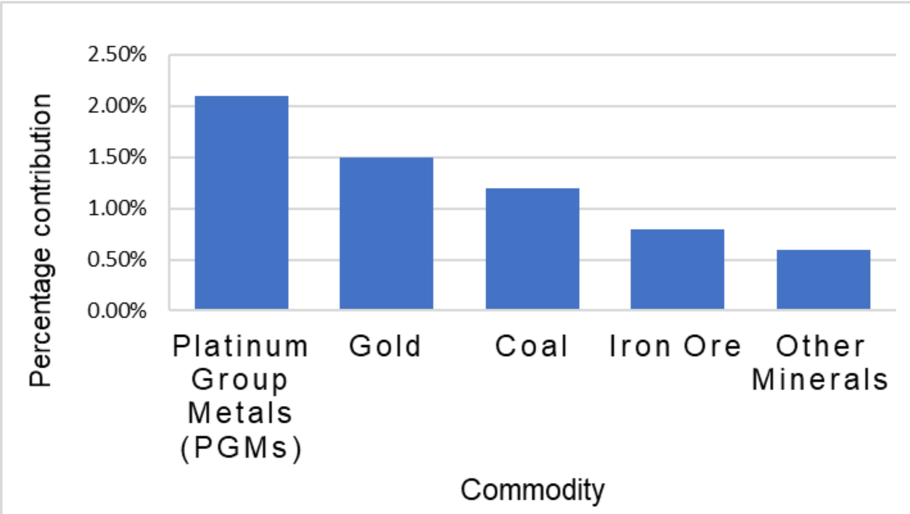

Figure 1: Mining percentage contribution to GDP

(Source: Minerals Council South Africa, 2023)

Nationally, coal mining contributed approximately ZAR198.9 billion to South Africa's total mining income in 2022, accounting for 21.9% of the total income from mining. While specific provincial data is limited, Mpumalanga—being the primary coal-producing region likely accounts for a significant portion of this revenue. This substantial inflow underscores coal's role as a vital economic driver in both the provincial and national economies. The revenue generated has also been instrumental in infrastructure development and government income through taxes, royalties, and other contributions, funding public infrastructure projects and social welfare programmes. In 2023, coal mines produced 231.7 million tonnes, amounting to USD252.3 billion in total sales and USD136 billion in export earnings (Minerals Council South Africa, 2023). Global demand, especially from emerging economies, has provided opportunities for continued export growth, further strengthening the trade balance and supporting overall economic development (Ebenhart, 2011).

Beyond revenue, the coal mining sector has been a major source of employment. As of June 2022, the coal and lignite mining sector employed approximately 95 863 individuals, representing 22.6% of total mining industry employment (Statistics South Africa, 2023). These jobs are critical for local livelihoods and regional development, particularly in coal-producing provinces. Figure 2 shows the number of people employed by the coal mining sector over time alongside earnings data.

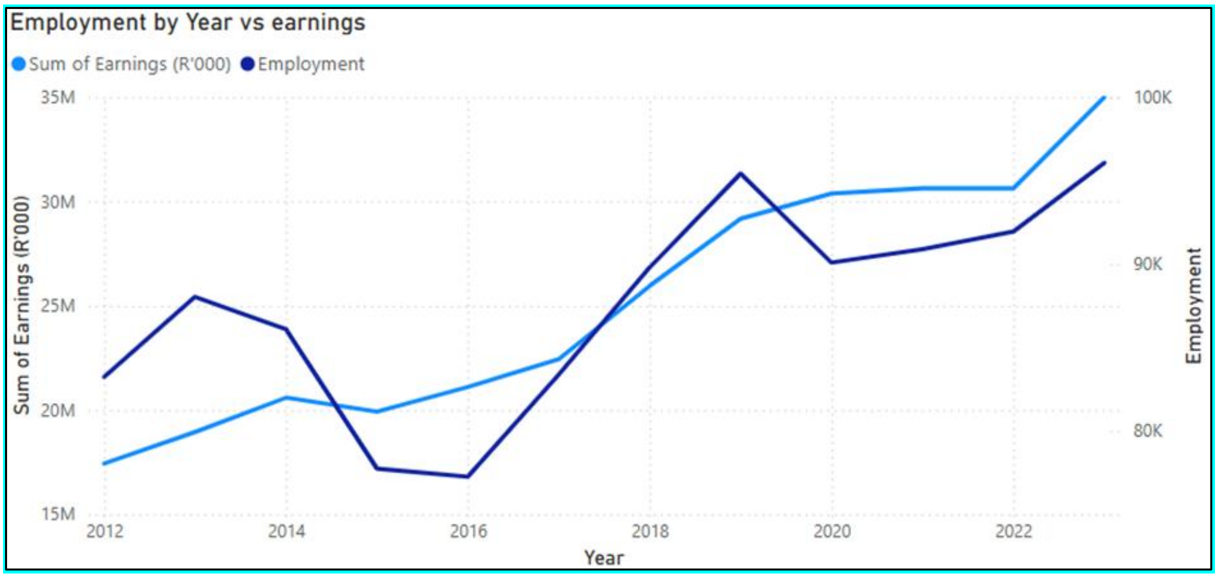

Figure 2: Employment vs earnings

(Source: Minerals Council South Africa, 2023)

Moreover, the sector supports additional jobs indirectly in industries such as transportation, machinery manufacturing, and services. According to Fleming & Measham (2014), for every direct mining job, approximately 1.4 additional local jobs are created in related service sectors, representing a 140% employment multiplier in mining regions. This multiplier effect underscores how the coal industry's employment impact extends well beyond direct operations, stimulating job creation and income generation across multiple sectors of the economy.

On a national scale, South Africa's economy remains deeply intertwined with the coal industry. In 2023, coal accounted for 96% of the country's energy production, including exports, highlighting its dominance in the energy sector (Statistics South Africa, 2023). This reliance on coal underscores its strategic importance in meeting domestic energy needs and maintaining economic stability. The continued dependence on coal-fired power generation also poses significant challenges for transitioning to cleaner energy sources while ensuring uninterrupted electricity supply. Figure 3 illustrates employment trends alongside coal production volumes over the years.

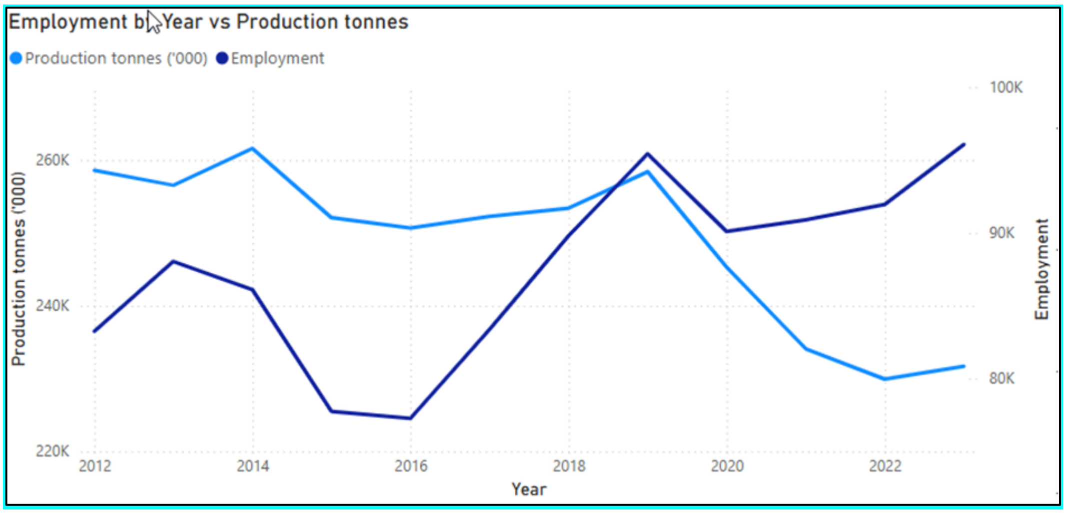

Figure 3: Employment vs production tonnes

(Source: Minerals Council South Africa, 2023)

2.4. The Energy Transition

The energy transition concept represents one of the most critical and transformative phenomena of the current generation. It encapsulates a fundamental reconfiguration of the global energy landscape, pivoting away from conventional, carbon-intensive energy sources towards cleaner, renewable alternatives. This transition has garnered immense attention in politics, economics, and environmental science due to its multifaceted global significance.

The energy transition is not a mere shift in energy technologies; it is a response to a convergence of pressing global challenges. At the forefront of these challenges is climate change. The overwhelming consensus among scientists and policymakers is that the combustion of fossil fuels is a primary driver of the rising global temperatures and the associated catastrophic consequences, making the decarbonisation of the energy sector a paramount objective (Bhattarai *et al*., 2022).

Simultaneously, the energy transition addresses issues of energy security, economic opportunity, public health, and sustainability. The reliance on finite fossil fuel resources from geopolitically unstable regions poses vulnerabilities to national and global energy security. Conversely, the shift towards renewable energy diversifies energy sources, reducing dependence on specific regions and enhancing resilience (Scrase & Ockwell, 2010). Furthermore, the energy transition creates new economic opportunities. As nations invest in renewable energy technologies, they stimulate innovation, create jobs, and establish competitive advantages in emerging green markets. This transition contributes to economic growth, fosters technological advancements, and nurtures a sustainable and inclusive future (Konisky & Carley, 2020).

It is also imperative to recognise the implications of coal on public health. Fossil fuel combustion is intrinsically linked to air and water pollution, which not only degrade environmental quality but also endanger human well-being. A transition to cleaner energy sources represents a significant stride toward mitigating these health hazards (Adu-Gyamfi *et al*., 2022). Additionally, the energy transition places sustainability at its core. Unlike fossil fuels, renewable sources such as solar, wind, and hydroelectric power are replenishable and have lower environmental footprints. Their utilisation is central to building a more sustainable future and ameliorating the strain on the planet's finite resources.

Despite these advantages, renewable energy sources also have some disadvantages. One of the main disadvantages is their intermittency and variability in power output, which can make it difficult to integrate them into existing energy systems. For example, solar and wind power are dependent on weather conditions, and their output can fluctuate rapidly. To address this challenge, new technologies such as energy storage and smart grids are being developed to help balance supply and demand and ensure a reliable and stable energy supply. The mining implications of lithium and cobalt on the environment is also an issue of concern that tends to be overlooked (Beales *et al*., 2021).

Recognising the challenges posed by this energy transition, South Africa has been the recipient of international funding aimed at supporting its shift towards renewables. Notably, during the 2021 COP26 summit, a coalition of developed nations, including the United States, the European Union, and the United Kingdom, pledged $8.5 billion while Denmark, the Netherlands and Spain pledged $3.5 billion and the World Bank recently advancing $1 billion to assist South Africa in accelerating its energy transition

(Climate Action Tracker, 2023). This funding is earmarked for building renewable energy infrastructure, reducing dependence on coal, and addressing the socio-economic consequences of the transition. However, while the funding provides a financial cushion, the conditions attached to it such as prioritising the expansion of renewables and the gradual phasing-out of coal present several challenges.

Harichandan, *et al.* (2022) conducted a comprehensive bibliometric analysis of energy transition research spanning four decades from 1981 to 2021. Utilising VOSviewer, CiteSpace, and R-Biblioshiny, they examined publications from Scopus and Web of Science databases. The analysis highlighted a growing emphasis on themes like climate change, alternative energy sources, governance strategies, and emission reduction. The authors identified critical areas for future research, including the development of policy frameworks, enhancement of energy infrastructure, notably storage and transfer systems, expansion of renewable energy ecosystems, economic analyses of clean energy, and comprehensive impact assessments. They advocate for increased international collaboration and knowledge sharing to expedite the global shift towards sustainable energy systems. The subsequent section discusses the analysis of policies and initiatives affecting the energy transition in South Africa.

2.5. Policies and Initiatives Affecting the Energy Transition in South Africa

Energy transition policies and initiatives have gained momentum in response to both domestic and international concerns about sustainability, environmental impact, and energy security. Several key policies and initiatives have been introduced to steer the country towards a more diversified and sustainable energy mix. These are discussed in the following subsections.

2.5.1. Integrated Resource Plan

South Africa developed an Integrated Resource Plan (IRP) in 2019 to outline its energy sector's future trajectory, including electricity generation sources and energy mix. The IRP 2019 was later updated in 2023 as a draft IRP 2023. IRP serves as a guideline for the country's energy planning and aims to ensure a balanced, sustainable, and cost-effective energy supply. The plan focuses on a diversified energy mix, aiming to reduce reliance on a single energy source. It promotes a combination of renewable energy sources, such as wind, solar, and hydroelectric power, natural gas, nuclear energy, and coal with cleaner technologies. There is a significant emphasis on increasing the share of renewable energy in the country's energy mix. The aim is to increase renewable energy capacity to contribute a substantial portion of the electricity supply by the year 2030 and a more increased capacity of renewables by 2050 (Department of Mineral Resources and Energy, 2024). As much as coal has been a primary energy source in South Africa, IRP 2023 outlined a gradual reduction in coal-generated power and a move towards cleaner energy sources due to environmental concerns and a global shift towards cleaner energy production (Department of Mineral Resources and Energy, 2024). Table 1 shows the proposed IRP targets in the next years.

Table 1: Installed capacity in IRP reference case

(Source: Department of Mineral Resources and Energy, 2024)

Technologies (GW)	2025	2030	2040	2050
Coal	39.6	32.4	21.8	10.6
Nuclear	1.9	1.9	1.9	0.0
Open Cycle Gas Turbines	3.5	9.1	15.2	28.8
Auxiliary Steam Turbine Generators	0.0	1.8	7.6	12.0
RMIPPPP	0.2	0.6	0.6	0.0
Solar PV	7.8	18.4	26.3	32.5
Solar CSP	0.5	0.6	0.6	0.1
Wind	3.5	8.3	23.4	42.0
Battery storage	0.2	3.5	6.6	12.0
Pumped hydro	2.9	2.9	2.9	2.9

IRP typically outlines the phased deployment of different energy sources over specific periods, considering factors like technological advancements, cost-effectiveness, environmental impact, and electricity grid stability. It details the planned capacity additions, indicating how much energy will be generated from each energy source within set timeframes (Department of Mineral Resources and Energy, 2024). As stated above, a significant focus of IRP is on integrating renewable energy sources into the grid and the plan typically includes procurement programmes like REIPPP to incentivise private sector involvement in renewable energy projects. These programmes encourage the development of renewable energy infrastructure through competitive bidding processes, bringing in private investments to expand renewable energy capacity.

In line with global efforts to mitigate climate change, IRP emphasises reducing carbon emissions and promoting cleaner energy technologies. It recognises the importance of transitioning to low-carbon or zero-carbon sources to minimise the environmental impact associated with energy generation as agreed upon during the Paris agreement in 2015 (Dimitrov, 2016). The Paris agreement is a legally binding international treaty on climate change. It was adopted by 196 parties at the United Nation (UN) Climate Change Conference (COP21) in Paris, France, on 12 December 2015 (Klein *et al.*, 2017). It entered into force on 4 November 2016, and South Africa is one of the signatories. The IRP also considers the social and economic implications of the energy transition. It emphasises the need for a "just transition," ensuring that workers and communities reliant on industries affected by the shift, such as coal mining, are supported in adapting to alternative economic activities. This includes initiatives for skills development, job creation, and community development (Department of Mineral Resources and Energy, 2019).

Implementing IRP involves coordination between government departments, regulatory bodies, energy authorities, and stakeholders. Regular monitoring, evaluation, and revision of the plan are essential to adapt to changing technologies, market dynamics, and emerging energy trends (D'Sa, 2005). IRP serves as a comprehensive roadmap guiding South Africa's energy transition, aiming to achieve a sustainable, reliable, and inclusive energy system. Its successful implementation requires collaboration between the public and private sectors, regulatory certainty, investments in infrastructure, and a commitment to environmental sustainability and social equity.

2.5.2. Renewable Energy Independent Power Producer Procurement Programme

REIPPP is an initiative in South Africa that aims to encourage private investment in renewable energy generation. It was launched to diversify the country's energy sources, reduce reliance on fossil fuels, and promote sustainable energy development. The programme, initiated in 2011, has undergone various rounds of procurement since then. The primary goal is to procure renewable energy from independent power producers (IPPs) through a competitive bidding process (McDaid *et al*., 2016). The programme focuses on various renewable energy technologies, including wind, solar photovoltaic (PV), concentrated solar power (CSP), biomass, biogas, and small-scale hydroelectric power (Department of Mineral Resources and Energy, 2019). The Department of Mineral Resources and Energy (DMRE) conducts competitive bidding rounds where IPPs submit proposals to develop renewable energy projects. Selection of bids is based on various criteria such as cost, technical feasibility, economic development, and job creation.

Successful bidders enter into long-term power purchase agreements (PPAs) with the government, guaranteeing the purchase of electricity generated by these renewable energy projects over a specified period (IPP Projects, 2023). Both domestic, international and private entities, are eligible to participate in the bidding process, fostering private sector involvement in renewable energy development. The programme aims to stimulate economic growth and create job opportunities, particularly in rural areas where many renewable energy projects are located. The programme has been conducted in several phases, with each phase inviting bids for various renewable energy technologies and capacity. The programme has been widely regarded as successful in attracting private investment in South Africa's renewable energy sector, contributing significantly to the country's energy mix while advancing its sustainability goals. It has brought in clean energy projects and has encouraged innovation, helping South Africa to diversify its energy sources and reduce its carbon footprint (IPP Projects, 2023).

2.5.3. Carbon Tax Act

The Carbon Tax Act in South Africa was implemented as part of the country's efforts to mitigate climate change and reduce carbon emissions. It came into effect on June 1, 2019, following the passing of the legislation by the South African government. The primary aim of the Carbon Tax Act is to put a price on carbon emissions, thereby encouraging companies to reduce their greenhouse gas emissions and transition toward cleaner, more sustainable practices. The Act imposes a tax on carbon dioxide (CO_2) equivalent emissions produced by various industries and sectors. The tax is applied to entities that exceed the prescribed thresholds for emissions. Initially, the tax rate was set at R120 per tonne of carbon dioxide equivalent emissions. However, certain allowances, tax-free thresholds, and tax incentives were introduced to ease the transition for businesses and sectors affected by the tax.

The Carbon Tax Act includes various allowances and tax-free thresholds aimed at reducing the tax burden on companies. These allowances consider factors such as process emissions, trade-exposed sectors, and performance benchmarks. Covered entities are required to measure and report their greenhouse gas emissions to determine their tax liability accurately. Compliance with the reporting requirements is necessary to ensure adherence to the legislation. The revenue generated from the carbon tax is intended to be used to support initiatives aimed at reducing greenhouse gas emissions and transitioning toward a more sustainable, low-carbon economy. This includes funding for renewable energy projects, energy efficiency programmes, and other climate change mitigation measures (South African Government, 2019).

The South African Revenue Service (SARS) oversees the administration and enforcement of the Carbon Tax Act. The overarching objective of the Carbon Tax Act is to drive a reduction in carbon emissions and promote a transition towards cleaner, more sustainable production methods. By pricing carbon emissions, the Act encourages industries to adopt cleaner technologies, improve energy efficiency, and invest in renewable energy sources, thereby contributing to the country's climate change commitments and global efforts to limit global warming.

The Carbon Tax Act reflects a proactive step by the South African government to align economic activity with environmental sustainability. By incorporating allowances and thresholds, the Act recognises the operational realities faced by different industries, especially those exposed to global competition. This shows a balanced approach, encouraging emission reductions without undermining economic stability. The mandatory reporting requirements are particularly commendable, as they enforce transparency and accountability. However, their effectiveness depends on the integrity of the monitoring systems and the enforcement capacity of regulatory bodies. Using tax revenue to support renewable energy and other green initiatives is a strong policy move. It not only mitigates environmental harm but also promotes innovation and job creation in the green economy. For long-term success, though, it is essential that the allocation of these funds is transparent, well managed, and targeted toward impactful projects. Overall, the Act is a constructive tool for climate action, and with strong implementation, it can drive meaningful progress toward South Africa’s low-carbon development goals.

2.5.4. Just Energy Transition Framework

The concept of a "Just Energy Transition" (JET) in South Africa refers to the country's commitment to transitioning from a fossil fuel-based economy, particularly coal, to a more sustainable and cleaner energy system while ensuring that the process is fair, inclusive, and socially equitable for all stakeholders involved. This transition acknowledges the need to address both environmental concerns, such as climate change mitigation, and social considerations, including the impact on workers and communities dependent on industries affected by the shift away from coal (Wang & Lo, 2021).

A comprehensive understanding of the social and economic implications of transitioning away from coal is essential. Assessments are conducted by government agencies, environmental organisations, mining companies, and independent research institutions to evaluate the potential impacts on workers, communities, and regions reliant on coal-related industries are typically conducted (Jordan & Tenzing, 2024). This includes identifying potential job losses, economic disruptions, and social challenges that might arise. The JET framework emphasises the importance of skills development and retraining programmes for workers affected by the declining coal industry (Wang & Lo, 2021). Efforts are made to equip affected individuals with the necessary skills to transition to new employment opportunities in emerging sectors, such as renewable energy, energy efficiency, and other green industries. Additionally, initiatives are undertaken to create new jobs in these sectors to absorb displaced workers (Bulmer *et al*., 2021).

The transition aims to support affected communities by implementing development programmes and projects that diversify local economies. Investments in infrastructure, education, healthcare, and other essential services are prioritised to ensure that communities reliant on coal industries have access to sustainable economic opportunities and social support systems (Bulmer *et al*., 2021). The rights of workers impacted by the transition are safeguarded, including considerations for fair labour practices, retraining, social security, and the protection of livelihoods. Social dialogue between government, industry stakeholders, labour unions, and affected communities is encouraged to facilitate consensus.

Government policies and initiatives are formulated to align with the principles of a JET. This includes incorporating considerations for social equity and environmental justice into energy and economic policies (Newell & Mulvaney, 2013). Supportive measures such as financial assistance, targeted investments, and policy incentives are implemented to facilitate a smoother transition and mitigate potential hardships. Collaboration between government, industry, labour unions, civil society, and affected communities is crucial for the success of the JET. Engaging stakeholders in the decision-making process fosters transparency, inclusivity, and shared responsibility in shaping the transition pathway (Wang & Lo, 2021).

The JET framework in South Africa aims to balance the imperative of addressing climate change and environmental concerns with the need to ensure that the transition is fair and does not disproportionately burden workers and communities dependent on coal-related industries. It aligns with global efforts to achieve sustainable development goals while promoting social equity and economic resilience. The goal of the transition is to ensure that no one is left behind (Department of Forestry, Fisheries, and the Environment, 2022). The JET framework is a commendable and necessary response to the dual challenge of decarbonising the economy while safeguarding the socio-economic fabric of affected communities. Its emphasis on fairness, social equity, and inclusive growth reflects an understanding that climate action must be holistic and not just environmentally sound, but socially just. However, while the framework presents an ambitious and morally sound vision, several aspects warrant closer scrutiny. One concern is the extent to which it has been operationalised. Although the framework outlines broad objectives, there remains a lack of clarity around implementation mechanisms, timeframes, and measurable targets. Without clear benchmarks, it becomes difficult to assess progress and hold stakeholders accountable.

Additionally, questions remain about the inclusivity and depth of stakeholder engagement during the formulation of the framework. While it is stated that there were consultations, it is not always clear whether these engagements meaningfully included all affected groups, especially workers at the grassroots level, small-scale enterprises, and local municipalities that may lack the capacity to navigate or implement transition policies effectively. There is a risk that top-down planning may miss the lived realities of those most vulnerable to economic shifts. Another area that could benefit from greater attention is the diversification of local economies currently reliant on coal. The framework speaks of "no one left behind," but it needs stronger support mechanisms, such as reskilling programs, education initiatives, and long-term investment in alternative industries to ensure sustainable livelihoods for these communities. In essence, the JET framework is a strong step in the right direction, aligning South Africa with international climate justice efforts. However, for it to succeed, the government must ensure transparent, inclusive policymaking and follow through with robust, well-funded implementation plans that address the complexities of local contexts.

2.5.5. National Development Plan

The National Development Plan (NDP) is a strategic roadmap for South Africa's long-term socio-economic development. It was introduced by the South African government as a blueprint to address various challenges and achieve specific goals by the year 2030. The NDP was formally approved in 2012 and covers various sectors and priorities focused on building a more fair, inclusive, and prosperous society (National Planning Commission, 2012). The NDP focuses on fostering economic growth by addressing structural challenges, promoting investment, and creating employment opportunities. It sets ambitious targets for reducing unemployment and poverty while aiming for higher rates of economic expansion. The most important aspect of the plan is enhancing the standard of education and enhancing skills development. It aims to ensure that all citizens have access to quality education and training to enhance employability and productivity. The NDP seeks to improve healthcare services, reduce the burden of disease, and ensure access to quality healthcare for all South Africans. It emphasises the need for social protection programmes to address poverty and vulnerability (National Planning Commission, 2012).

The priority of the NDP is to enhance infrastructure across various sectors, including transportation, energy, water, and Information Communication Technology (ICT) (National Planning Commission, 2012). This includes both physical infrastructure projects and digital connectivity to support economic growth and development. The plan emphasises rural development initiatives and addresses land reform issues. It aims for equitable access to land and opportunities for rural communities (National Planning Commission, 2012). The NDP highlights the importance of promoting social cohesion, reducing social divisions, and building a united South African identity. It emphasises inclusivity and unity across diverse communities. Acknowledging the significance of sustainable development, the NDP seeks to align economic growth with environmental conservation and natural resource conservation (National Planning Commission, 2012).

NDP serves as a guide for policy formulation, resource allocation, and monitoring progress towards achieving its outlined goals. It has been subject to reviews and adaptations to address emerging challenges and ensure alignment with changing circumstances. However, challenges in implementation, such as funding constraints, governance issues, and socio-political dynamics, have impacted the full realisation of the plan's objectives. Regular assessments and adjustments are necessary to advance towards the NDP's vision. The impacts of energy transition on coal sectors in other countries are discussed in the next section.

2.6. Impacts of Energy Transitions on Coal Sectors in Other Countries

This section discusses the impacts of the energy transition on the coal sector in Germany, the United Kingdom (UK), United States of America (USA), China and Denmark. These countries represent a diverse approach to coal phase-out and sustainability strategies. These five countries were selected based on their historical and ongoing coal production and consumption. Germany exemplifies a structured coal phase-out approach through its *Energiewende* policy, aiming for complete coal exit by 2038 while maintaining energy security (Haas *et al*., 2022). UK, once a leading coal-powered economy, has nearly eliminated coal from its energy mix, setting a precedent for rapid coal phase-out in industrialised nations (Rentier *et al*., 2019). USA, historically the second largest coal producer, has witnessed a steady decline in coal due to economic shifts and the rise of natural gas and renewables (Liu *et al*., 2023). China is the world's largest producer and consumer of coal, accounting for over 50% of the global coal demand (Ma *et al*., 2021). This makes China's transition strategies critical to global climate goals. Denmark, a leader in renewable energy, offers a unique case of coal phase-out driven by ambitious climate policies and wind energy expansion (Danish Ministry of Climate, Energy and Utilities, 2018). By analysing these case studies, this section provides insights into policy-driven transitions, economic implications, and technological adaptations within the coal sector. The next subsections discuss these case studies.

2.6.1. Germany

Germany's energy transition, known as Energiewende which translates to "energy turnaround" or "energy transition", has had substantial impacts on its coal sector. The country has been actively phasing out coal as part of its efforts to shift towards renewable energy sources and reduce greenhouse gas emissions. Germany has significantly reduced its reliance on coal for electricity generation. Policies aimed at promoting renewable energy sources, along with the imposition of carbon pricing and environmental regulations, have led to the closure of coal-fired power plants. The declining demand for coal in the power sector has resulted in a notable decrease in coal-based electricity production (Oei *et al*., 2020). Figure 4 shows Germany's electricity mix (in %) over a 10-year period.

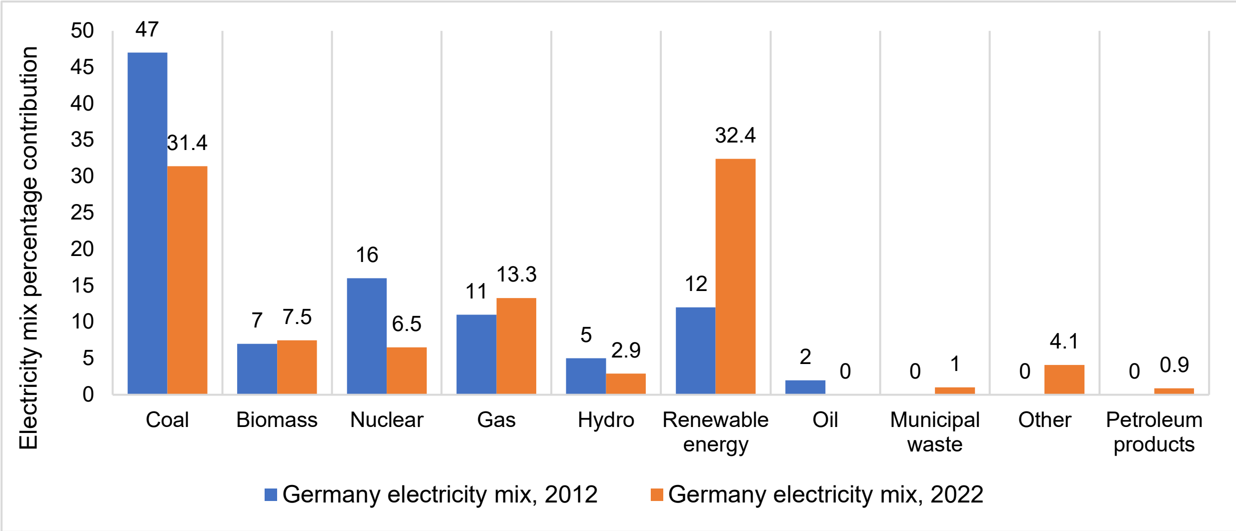

Figure 4: Ten-year difference in the German electricity mix

(Source: Statista, 2023)

Electricity generation from coal has reduced by 33% while electricity generation from renewable resources has increased by 170% over the past 10 years as shown in Figure 4 (Statista, 2023). Germany's coal mining sector has experienced a significant decline in employment over recent decades, primarily due to the closure of coal-fired power plants and the nation's commitment to phasing out coal by 2038. In 1990, approximately 130,000 individuals were directly employed in the coal industry. By 2021, this number had decreased to around 6,670, representing an approximate 94.9% reduction in direct coal mining employment over 31 years (German Extractive Industries Transparency Initiative (D-EITI), 2023)

The government of Germany has implemented measures to support affected workers and communities, including financial assistance and retraining programmes (Oei *et al*., 2020). The energy transition has prompted efforts to diversify regional economies previously reliant on coal. Investments in renewable energy projects, research, and innovation have encouraged the creation of new economic opportunities in affected areas. Strategies for sustainable economic development, including the revitalisation of former coal regions, are being pursued to mitigate the socio-economic impacts of the coal phase-out (Matern *et al.,* 2022).

Despite significant progress, challenges exist, such as the need for better storage solutions to manage intermittent renewable energy, the cost of the transition, grid integration issues, and balancing environmental concerns with economic competitiveness. Additionally, concerns about the reliability of energy supply and rising electricity costs have prompted policymakers in Germany to adjust energy policies and regulatory frameworks to address these issues while maintaining the transition's objectives (Röhrkasten *et al*., 2016). These impacts underscore the complex interplay between energy policies, economic restructuring, social considerations, and environmental goals in Germany's transition away from coal. The country's experience provides insights into the challenges and opportunities associated with phasing out coal while fostering a more sustainable and diversified energy landscape.

2.6.2. United Kingdom

UK has been undergoing a significant energy transition, marked by efforts to reduce coal dependency and increase renewable energy sources. The impacts on the coal sector in the country have been substantial. UK has witnessed a marked reduction in coal-based electricity generation. Policies promoting renewable energy, coupled with carbon pricing mechanisms and regulatory measures, have led to the closure of numerous coal-fired power plants. This shift has resulted in a substantial decrease in the share of coal in the country's electricity generation mix (Rentier *et al*., 2019). Figure 5 illustrates UK’s energy mix (in %) over a 10-year period.

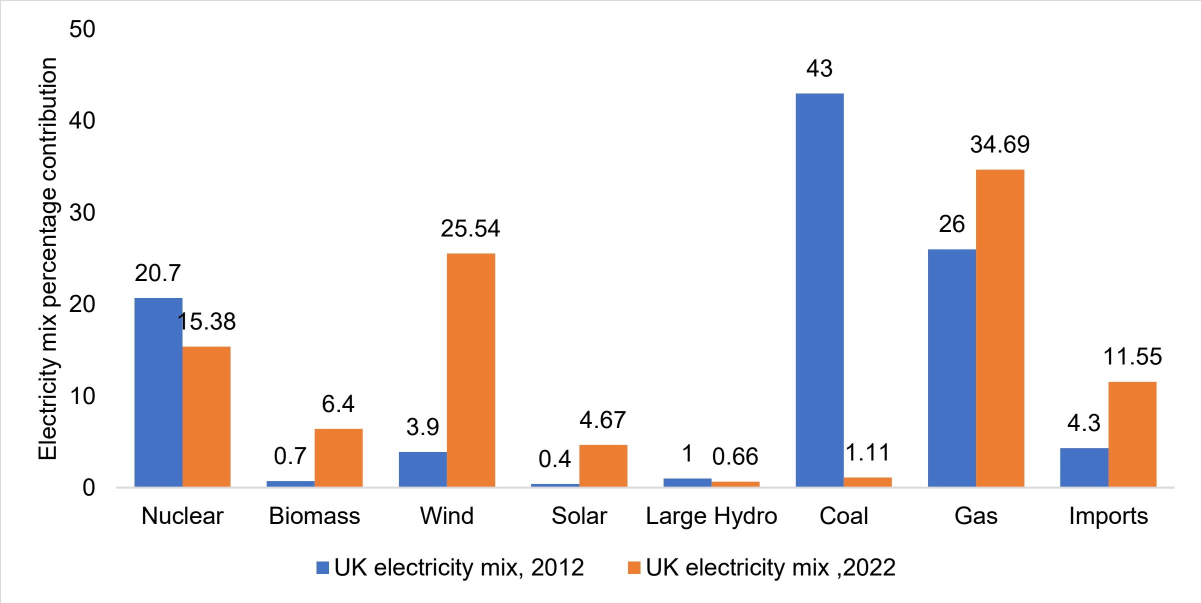

Figure 5: Ten-year difference in the UK electricity mix

(Source: MyGridGB, 2023)

As illustrated in Figure 5, electricity generation from coal reduced significantly over the 10-year period from 43% in 2012 to 1.11% in 2022, equating to a 97.4% reduction. Generation of electricity from wind and solar increased by 554.8% and 1067.5%, respectively while the use of gas and imports slightly increased by 33.4% and 168.6%, respectively. While emphasising renewables, UK maintains nuclear power as part of its low-carbon energy mix. Plans for the development of new nuclear power plants have been part of the country's strategy to ensure a diverse energy portfolio.

The closure of coal mines has had significant impacts on the coal mining industry, leading to job losses and structural changes in coal-dependent regions. Efforts have been made to support affected workers and communities through transition schemes and financial assistance programmes (Strambo *et al*., 2019). The transition away from coal in UK has spurred investments in renewable energy infrastructure, such as wind, solar, and biomass. This growth in renewable energy capacity has contributed to diversifying the energy mix and reducing reliance on coal. The country has been a global leader in offshore wind energy. It has set ambitious targets to significantly increase offshore wind capacity, aiming for 50 gigawatts (GW) by 2030 (UK Government, 2023). The government has incentivised the development of clean energy projects to replace coal-fired power generation (Elliot, 2019).

UK has implemented measures to improve energy efficiency, particularly in buildings and industries. Stricter building standards, energy-saving initiatives, and the promotion of energy-efficient technologies have been key focus areas (Department for Business, Energy & Industrial Strategy, 2020a). The country aims to accelerate the transition to electric vehicles (EVs) by phasing out petrol and diesel cars by 2030. Investments in EV infrastructure, grants for EV purchases, and incentives for low-emission vehicles are part of this initiative. The UK government has set ambitious targets to achieve net-zero greenhouse gas emissions by 2050 (Department for Business, Energy & Industrial Strategy, 2020b). Key policy documents such as the Energy White Paper and the Ten Point Plan for a Green Industrial Revolution outline strategies and commitments for the energy transition. Investment in research and innovation plays a crucial role in developing cleaner energy solutions and advancing technologies. Focus areas include energy storage, smart grid technologies, carbon capture and storage (CCS), and other innovative solutions to support the transition (Department for Business, Energy & Industrial Strategy, 2020b).

The shift from coal to alternative energy sources has presented challenges, including concerns about energy security and the need for electricity grid stability. Economic restructuring in regions historically reliant on coal has been a focal point, with initiatives aimed at creating new economic opportunities, promoting skills development, and supporting the transition to a low-carbon economy (Bang *et al*., 2022). The UK government's policies and commitments, such as the Clean Growth Strategy and the Industrial Strategy, outline plans to support clean energy transition, innovation, and the development of new technologies. These policies aim to facilitate the phasing out of coal while ensuring a sustainable and resilient energy future (Sunley *et al*., 2022).

The impacts of the energy transition in the UK highlight the complex challenges and opportunities involved in reducing coal dependency while promoting a more sustainable and diversified energy system. UK's experience offers valuable insights into managing the social, economic, and environmental dimensions of moving away from coal. Importantly, according to Paterson (2024), this transition began in the 1980s during Prime Minister Margaret Thatcher's tenure, when a series of coal mine closures were enacted. These closures were driven not only by environmental considerations but also as a political strategy aimed at diminishing the influence of National Union of

Mineworkers (NUM) (Paterson, 2024). This period marked a significant turning point in the UK’s energy policy, laying the groundwork for broader structural changes in the country’s energy sector.

2.6.3. United States of America

In USA, the energy transition has resulted in significant changes in the coal sector, influenced by market forces, technological advancements, and environmental policies. USA has experienced a substantial decrease in coal-fired power generation due to several factors, including increased competition from natural gas, declining costs of renewable energy, and environmental regulations. Many coal-fired power plants have closed or undergone conversions to cleaner alternatives, leading to a significant reduction in coal's share of electricity generation (Gruenspecht, 2019). Figure 6 illustrates USA’s electricity mix (in %) over a 10-year period.

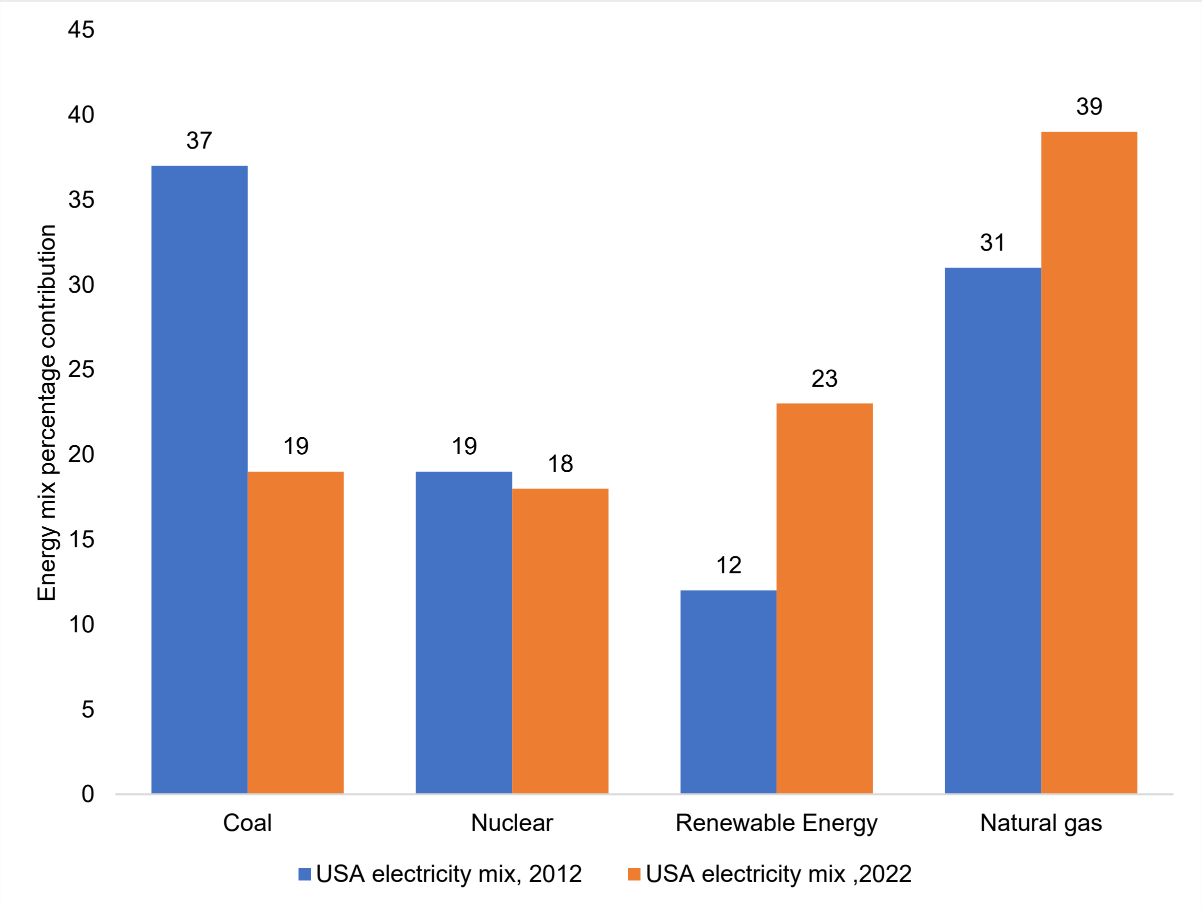

Figure 6: Ten-year difference in the USA electricity mix

(Source: World Economic Forum, 2023)

The use of coal in electricity generation has decreased by 48.6% from the year 2012 to the year 2022. It also shows that the use of natural gas and renewable energy in the electricity mix has increased by 25.8% and 91.7%, respectively. However, the use of nuclear energy reduced by 5.3%.

The decline in coal demand has impacted the coal mining industry, resulting in mine closures and job losses in coal-dependent regions. Efforts have been made to assist affected communities through retraining programmes and economic diversification initiatives (Chesmore *et al*., 2021). USA has seen a significant increase in natural gas usage for electricity generation, partly displacing coal. However, there has been increasing emphasis on reducing methane emissions from natural gas extraction and production due to its impact on climate change. Additionally, there has been substantial growth in renewable energy sources such as wind and solar, which have become more competitive in terms of cost and efficiency. Policies supporting renewable energy deployment have contributed to this shift (Magali & Montes-Sancho, 2011).

Federal and state-level initiatives encourage the adoption of renewable energy sources. Policies like Renewable Portfolio Standards (RPS) set targets for utilities to generate a specific portion of their energy from renewable sources (Agupugo *et al*., 2024). Federal incentives, such as Investment Tax Credits (ITC) and Production Tax Credits (PTC), have been crucial in boosting the renewable energy sector's growth (Agupugo *et al*., 2024). These initiatives focus on improving building standards, promoting energy-efficient appliances, and encouraging industrial and commercial energy-saving practices (Wiser *et al*., 2011). Furthermore, USA has been promoting the adoption of EVs, aiming to reduce greenhouse gas emissions from the transportation sector. Initiatives include incentives for EV purchases, investments in charging infrastructure, and support for research and development in EV technology.

The energy transition has posed economic challenges for coal-producing regions. Various federal and state-level policies have been proposed to support these communities, including initiatives for economic diversification, investment in infrastructure, and retraining programmes for workers transitioning out of the coal industry (Roemer & Haggerty, 2021). Additionally, some of the challenges facing the USA energy transition include the need for electricity grid modernisation, addressing intermittency issues with renewable energy, infrastructure upgrades, policy uncertainties due to changing political landscapes. These impacts highlight the multifaceted nature of the energy transition in the USA, reflecting changes in energy generation, employment patterns, environmental considerations, and the need for supportive policies to manage the transition's socio-economic effects on coal-dependent communities.

2.6.4. China

In China, the transition towards cleaner energy has greatly affected the coal industry, fuelled by initiatives to enhance air quality, lower carbon emissions, and move towards more sustainable energy sources. China, as the world's largest coal consumer, consuming over 50% of the world’s coal demand, has been actively working to decrease its reliance on coal (Ma *et al*., 2021). Policies aimed at curbing air pollution and transitioning to cleaner energy sources have led to a reduction in coal consumption. The Chinese government has implemented measures to limit the use of coal in industries and has been promoting cleaner alternatives (He *et al*., 2020). Figure 7 illustrates China’s electricity mix (in %) over a period of 10 years.

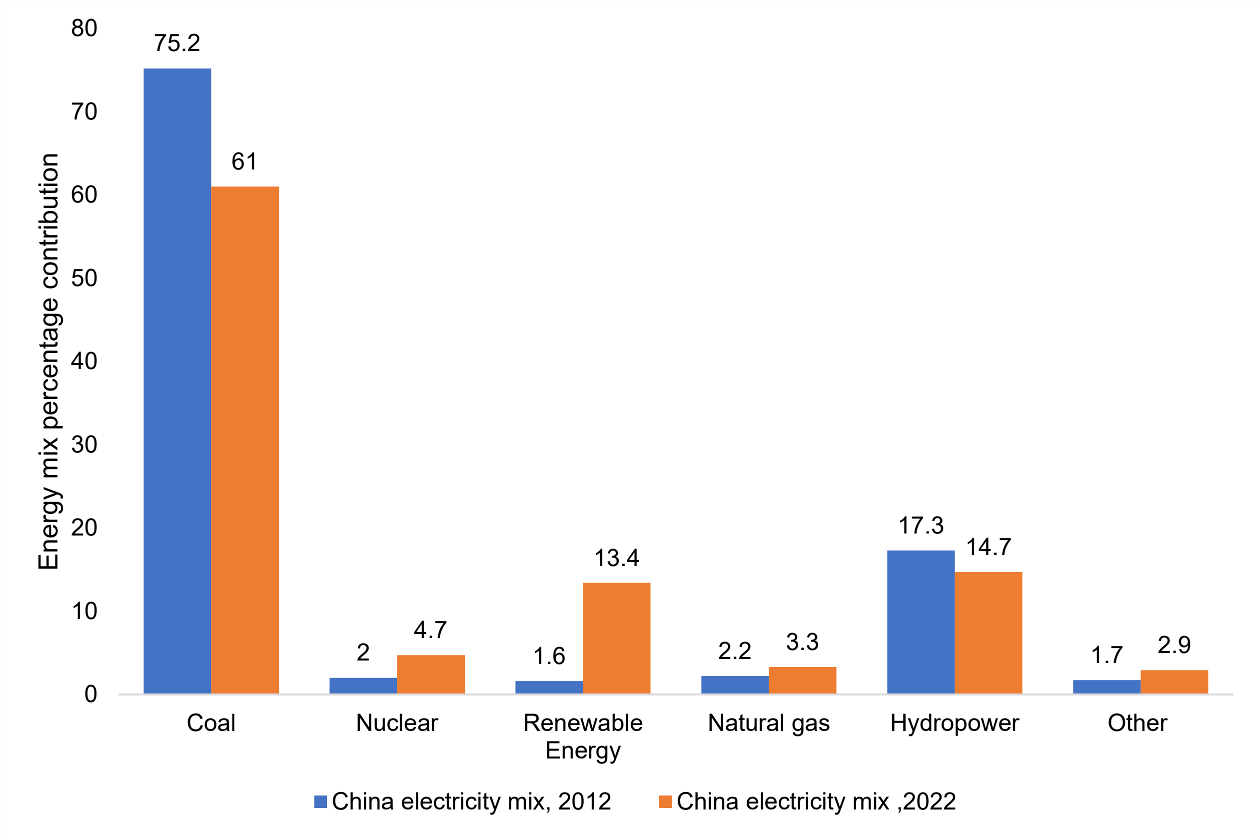

Figure 7: Ten-year difference in the China electricity mix

(Source: Ember, 2023)

Electricity generation from coal in China has reduced by 18.9% from the year 2012 to the year 2022. Electricity generation from renewable energy has increased 737.5%. To address overcapacity and improve environmental conditions, China has undertaken the closure of outdated and inefficient coal mines and coal-fired power plants. The closure of these facilities has led to a decrease in coal production and a shift towards more efficient and environmentally friendly coal mines and power plants (He *et al.*, 2020). China has been investing heavily in renewable energy sources like wind, solar, and hydroelectric power. The Chinese government has set ambitious targets for renewable energy capacity expansion, aiming to diversify the energy mix and reduce reliance on coal. Moreover, advancements in clean coal technologies and efforts towards CCS have been part of China's strategy to mitigate coal-related emissions (Wang *et al.*, 2020). The transition away from coal has presented economic challenges, especially in regions heavily dependent on the coal industry. Job losses and economic restructuring in coal-dependent areas have been significant concerns. Efforts have been made to support affected workers and communities through retraining programmes and measures aimed at fostering alternative economic activities (Zhao *et al*., 2022).

China is the leading global investor in renewable energy infrastructure and has consistently expanded its renewable energy capacity. The country aims to produce 35% of its electricity from non-fossil fuel sources by 2030. As mentioned earlier, it has made significant strides in growing its renewable energy sector through supportive policies, including feed-in tariffs and subsidies (He *et al*., 2020). In a landmark announcement, China pledged to achieve carbon neutrality by 2060. This commitment implies a monumental shift in its energy infrastructure, focusing on reducing greenhouse gas emissions significantly. To achieve this goal, China aims to peak its carbon emissions by 2030 and subsequently reduce them, primarily by transitioning to renewable energy sources, enhancing energy efficiency, and implementing carbon capture technologies (He *et al*., 2020).

China, Germany, UK, and USA actively participate in international forums and agreements related to climate change and energy transition, such as the Paris Agreement. As a signatory to this agreement, China has committed to reducing its carbon intensity and increasing the share of non-fossil fuels in its energy mix. China's participation in global dialogues and partnerships highlights its dedication to tackling climate change on an international level (Schreurs, 2016). These impacts in China illustrate the challenges and strategies associated with transitioning away from coal, emphasising the importance of clean energy development, technological innovation, and socio-economic considerations in achieving a more sustainable energy future.

2.6.5 Denmark

Denmark is globally recognised for its pioneering efforts in renewable energy and sustainable practices, particularly in wind power (Danish Ministry of Climate, Energy and Utilities, 2018). Denmark has been a leader in wind energy innovation and utilisation, making significant investments in both onshore and offshore wind farms, positioning itself as a global frontrunner in wind energy production. The country has set bold renewable energy goals, aiming to cut greenhouse gas emissions by 70% by 2030 and achieve carbon neutrality by 2050 (Barker *et al*., 2022). These goals align with the country's commitment to the Paris Agreement and reducing greenhouse gas emissions. Denmark's emphasis on energy efficiency extends to its district heating systems, which utilise waste heat from industries and power plants (Johansen & Werner, 2022). This efficient heating infrastructure reduces energy consumption in buildings and homes. Figure 8 illustrates Denmark's electricity mix (in %) over a period of ten years.

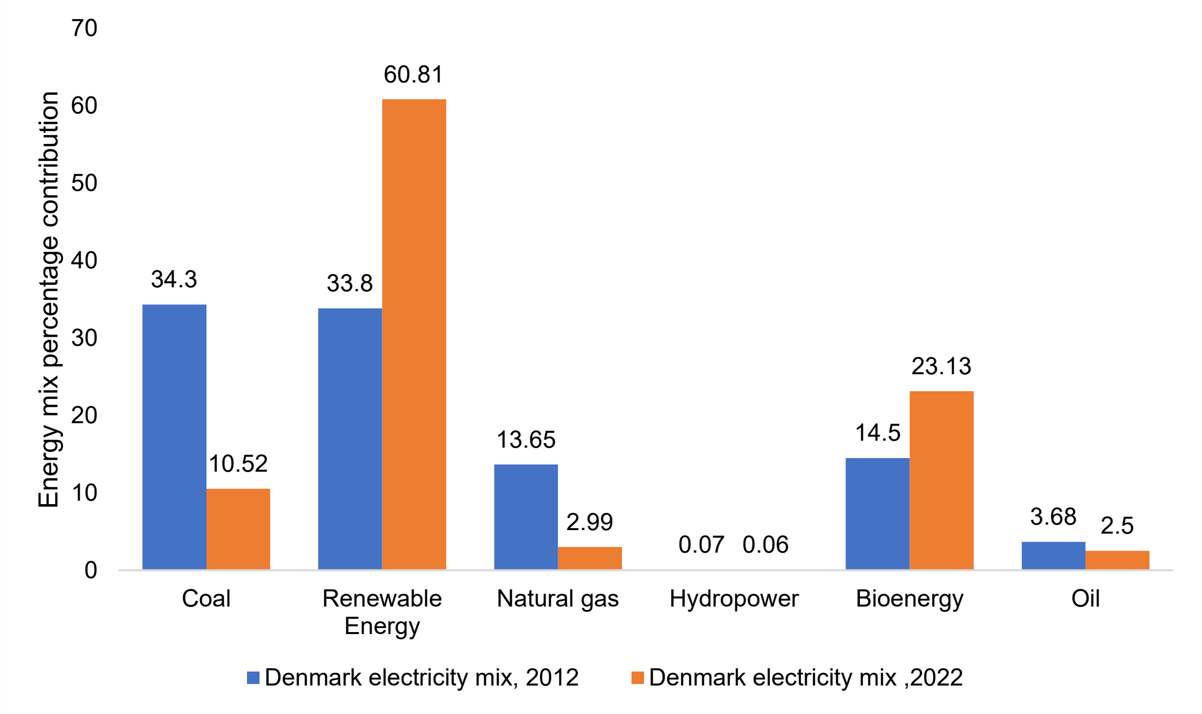

Figure 8: Ten-year difference in the Denmark electricity mix

(Source: International Energy Agency, 2022)

Electricity generation from coal reduced by 69.3% from the year 2012 to the year 2022. electricity generation from renewable energy has increased by 79.9% over the same period. The Danish country has established a robust policy framework supporting renewable energy development. The Energy Agreement of 2018 outlines specific measures and goals to increase renewable energy generation, reduce energy consumption, and promote sustainable practices (Ministry of Energy, Utilities and Climate, 2018). Denmark invests in smart grid technologies and energy storage solutions to manage the integration of intermittent renewable energy sources, ensuring grid stability and reliability (Lund *et al.*, 2022).

Denmark is committed to decarbonising the transportation sector by promoting EVs and investing in EV infrastructure, including charging networks and incentives to accelerate EV adoption (Kany *et al.*, 2022). Denmark's energy transition journey showcases a holistic approach encompassing renewable energy expansion, energy efficiency measures, supportive policies, innovation, and commitment to decarbonisation across various sectors. Challenges such as intermittency of renewable sources, storage solutions, infrastructure development, and ensuring affordability remain focal points for Denmark's ongoing energy transition (Saleh & Hassan, 2024).

2.6.6. Comparative analysis of national energy transitions

Table 2 provides a structured comparative analysis of national energy transitions across six countries in chronological order of beginning the transition. The table captures key dimensions of each country’s transition journey, including the timeline, major policies enacted, challenges encountered, and the resulting economic, environmental, and social impacts. The table also synthesises lessons learned from each country, offering insights into the effectiveness of different policy approaches and governance models.

Table 2: Summary of a comparative analysis of national energy transitions.

Country	Transition Period	Key Policies Implemented	Challenges Faced	Economic Impact	Environmental Impact	Social Impact	Lessons Learned
UK	1980s–present	Electricity Market Reform (EMR), Carbon Price Floor, closure of coal plants	Political opposition (miners' strikes), regional economic decline	Deep coal jobs dropped drastically post-1980s, shift to services sector	Coal use reduced from 70% (1990) to <2% (2020) of electricity	Social dislocation in mining communities, improved air quality	Political will and market mechanisms accelerate transition, early support lacking
Germany	1990s–present	Renewable Energy Act (EEG), Coal Phase-out Act (2020), Energiewende strategy	High costs of renewables, grid expansion, regional job losses	95% drop in coal mining jobs (1990–2021), €40bn committed to affected regions	Significant emissions reduction, rise in renewables share	Job losses in coal regions, structural aid programs initiated	Strong policy frameworks and long-term vision needed; social support critical
Denmark	1990s–present	Carbon tax, feed-in tariffs, Energy Agreements (2008, 2012, etc.)	High cost of early adoption, dependency on wind variability	Net job creation in renewables, wind industry export growth	70% of electricity from renewables (2022), emissions greatly reduced	Broad public support, energy access improved	Early policy action and consensus politics ensure stability and success
USA	2000s–present (varied by state)	Clean Power Plan (revoked), state-level RPS, IRA (2022)	Federal-state policy inconsistency, coal lobbying	Coal jobs declined sharply; renewable jobs increasing; Inflation Reduction Act promises green job boom	Local air quality improvement, CO_2 emissions decline in some states	Health benefits in transitioned regions; concerns in coal-reliant states	Decentralised governance can both enable and hinder transition
South Africa	2000s–present	Integrated Resource Plan (IRP), Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), JET-IP	Dependence on coal, Eskom's financial/operational instability, slow policy implementation	Coal remains dominant (80% of electricity); limited diversification; job risks in coal-dependent areas	Slow emissions reduction; high pollution in coal belts; emerging renewables sector	Job insecurity in coal regions, energy access inequalities, community resistance to closures	Need for clear, inclusive transition strategy; importance of community participation and energy justice
China	2010s–present	National Energy Administration policies, 14th Five-Year Plan, subsidies for solar/wind	Balancing economic growth and emission reduction, regional disparities	Large-scale investment in renewables, job shifts from coal to green energy	Massive solar/wind expansion; world's largest GHG emitter still	Mixed: improved air in urban areas, coal communities vulnerable	Scale and state-led coordination key; still need just transition measures

2.6.7. Comparative policy analysis: coal transition & renewable energy policies

In South Africa, energy transition policies often overlap because they are developed by multiple institutions with intersecting mandates, resulting in duplicated targets, conflicting timelines, and parallel implementation processes. For example, the IRP 2019 and Eskom's JET Strategy both outline coal plant retirement schedules but differ in timing and sequencing. Similarly, the Presidential Climate Commission's Just Transition Framework and the Just Energy Transition Investment Plan (JET-IP) each include socioeconomic measures for affected workers and communities, while Eskom runs its own reskilling and local development programmes, sometimes without full alignment. Climate commitments in the Nationally Determined Contribution (NDC) push for faster emissions reductions than the IRP's coal phase-out allows, creating tension between climate and energy security objectives. Renewable energy procurement under the REIPPPP and infrastructure funding under the JET-IP also target similar capacity additions but may be rolled out on different timelines or without synchronised grid-readiness planning. These overlaps can cause confusion for stakeholders, duplicated consultations, and fragmented investment planning, undermining the coherence and efficiency of South Africa's transition efforts.

Table 3 presents a consolidated cross-country comparison of coal phase-out and renewable energy policies in the UK, Germany, Denmark, USA, South Africa and China. It brings together key aspects of each country's approach, including policy development processes, socio-economic and political contexts, main regulatory and incentive mechanisms, stakeholder influences and positions, and anticipated sectoral impacts. By integrating these elements, the table offers both a concise overview and comparative insight into how different governance models, market instruments, and stakeholder dynamics shape energy transition pathways. This holistic perspective provides a foundation for drawing lessons that can inform future policy design and implementation in South Africa.

Table 3:Comprehensive policy comparison & stakeholder analysis

Country	Coal Phase-Out Target	Renewables Mechanism	Policy Development Process	Socio-Economic & Political Context	Key Policy Components	Stakeholder Influence & Position	Sectoral Impacts	Primary Policy Documents
UK	2024/25	Carbon Price Floor + Contracts for Difference (EMR)	EMR & CPF introduced 2013–2015 after market reform consultations; cross-party climate consensus; stakeholder input from industry, NGOs, labour unions	Low coal dependency; strong public climate support; energy price sensitivity during gas crises	Regulatory price floor; competitive CfDs for RE; coal plant closure schedule; offshore wind targets	DESNZ (High/Support), Ofgem (High/Support), unions (Moderate/Conditional), NGOs (Moderate/Support)	Rapid emissions decline; >40,000 RE jobs; temporary price volatility; grid stability manageable	EMR (2013), CPF legislation, UK Net Zero Strategy
Germany	By 2038 (aspiring 2030)	EEG: FIT → competitive auctions	Energiewende from early 2000s; 2019–2020 coal commission with broad consultations; federal & state alignment	Moderate coal dependency in lignite regions; high public RE support; strong co-op movement	FIT → auctions; coal exit law with compensation; RE expansion targets; citizen energy rights	BMWK (High/Support), IG BCE union (High/Oppose), NGOs (High/Support), utilities (Mixed)	40% RE share by 2022; coal region compensation; steady emissions drop	EEG (2000, amended 2014), Coal Phase-out Act (2020), Climate Protection Act

Denmark	2028 (all coal-fired plants closed)	Feed-in tariffs → competitive tenders; offshore wind auctions; green certificates	Long-term political consensus (Energy Agreements 2012, 2018); broad stakeholder involvement; compliance with EU directives; climate neutrality by 2045	Very low coal dependence (<10% by 2020); strong public RE support; high wind penetration; EU-aligned climate goals	Offshore wind expansion; carbon tax (since 1992, reformed 2022); coal plant decommissioning schedule; full power sector decarbonisation by 2035	Ministry of Climate, Energy and Utilities (High/Support); Ørsted (High/Support); municipalities (Moderate/Support); NGOs (High/Support); unions (Moderate/Conditional)	Rapid RE growth (wind >50% of electricity); minimal coal job losses; offshore wind supply chain job creation	Energy Agreements (2012, 2018); Climate Act (2020); Danish Energy Agency coal phase-out plan
USA	No federal phase-out; state targets	State RPS + IRA incentives	State-led RPS since late 1990s; IRA 2022 after congressional negotiations; federal–state energy jurisdiction split	Regional coal dependency in Appalachia; political polarisation; strong RE growth in coastal & midwestern states	Tax credits for RE & storage; grants; methane fees; state RPS mandates; EPA emissions rules (some revoked)	DOE (High/Support), EPA (High/Support), UMWA (High/Oppose), NGOs (Moderate/Support), utilities (Mixed)	CO_2 decline in power sector; clean energy job surge; coal job losses concentrated in few states	IRA (2022), State RPS laws, EPA Clean Power Plan (revoked)
South Africa	30% retire by 2030, 80% by 2050	REIPPPP competitive auctions; JET-IP social plans	IRP updates 2010–2019; REIPPPP launched 2011; JET-IP developed with JETP donors 2021–2022	High coal dependency (>80% power); coal regions economically reliant; fiscal constraints; load shedding crisis	Competitive IPP auctions; carbon tax (weak price); social plan under JET-IP; grid expansion plans	DMRE (High/Oppose), Eskom (High/Support), NUM (High/Oppose), NGOs (Moderate/Support), JETP donors (High/Support)	Potential >200 Mt CO_2 cut by 2050; ~300k coal jobs at risk; RE could add >250k jobs if grid built	IRP (2019), REIPPPP docs, Carbon Tax Act (2019), JET-IP (2022)
China	Phase-down from 2026	Subsidies + provincial capacity caps	NEA/NDRC-led policy cycles in 5-year plans; provincial adaptation; RE subsidy reforms since 2020	Heavy coal dependence: local economies tied to coal jobs; central policy sets vision, provinces adapt	Subsidies for wind/solar; provincial coal caps; green certificate trading; capacity auctions	NEA (High/Support), State-owned utilities (High/Mixed), provincial govts (High/Conditional)	Rising RE share; emissions peak before 2030; job risks in coal provinces	14th FYP (2021–2025), Renewable Energy Law (2005, amended 2015), provincial coal policies

2.7. Summary of Chapter 2

Chapter 2 presents a literature review that critically examines South Africa’s coal sector and its evolving energy transition. The chapter begins with a historical overview that emphasises the central role coal has played in the country’s electricity mix, particularly its contribution to industrialisation and economic development. Coal has historically been a cornerstone of South Africa's energy production, enabling the establishment of key industries and providing the bulk of the country’s electricity mix.

The review then transitions to an in-depth discussion of the economic contributions of the coal sector, outlining its important role in national energy production, employment generation, and industrialisation. Coal has been an important driver of South Africa’s economic growth, providing affordable and reliable energy that has supported sectors such as mining, manufacturing, and transportation. However, the review also acknowledges the challenges of this dependency, such as environmental concerns and the volatility of global coal markets, and how these factors have prompted shifts in energy strategies.

The chapter further explores the ongoing energy transition in South Africa, focusing on a range of policies and initiatives aimed at reducing the country's reliance on coal and promoting a shift to renewable energy sources. These include IRP, which outlines long-term strategies for energy generation, REIPPP designed to encourage private sector investment in renewable energy, and the Carbon Tax Act, which seeks to incentivise emission reductions across industries. Additionally, the JET framework is discussed, emphasising the need for a fair transition for communities and workers dependent on the coal industry. The NDP is also discussed, offering a roadmap for sustainable development that aligns energy, economic, and social goals.

These policies are assessed based on their ability to reshape South Africa's energy sector. The review emphasises the wider economic impacts of transitioning away from coal, such as challenges related to energy security, job losses, and the need for significant investment in renewable technologies. By focusing on the intersection of policy, economic growth, and sustainability, the chapter examines how these initiatives collectively aim to diversify South Africa's electricity mix and reduce its carbon footprint.

In addition, the chapter draws on international case studies summarised in Table 3 to provide comparative perspectives on energy transitions. It analyses the coal sector’s transformation in countries like Germany, UK, USA, China, and Denmark, drawing lessons from their experiences in managing coal phase-outs, scaling up renewable energy, and addressing socio-economic challenges. These case studies are instrumental in understanding the practical implications of energy transitions and offer valuable insights into the strategies that South Africa can adopt to navigate its own energy transition.

By combining historical context, economic factors, policy developments, and global case studies, this chapter provides a thorough understanding of the coal sector’s role in South Africa’s economy and its trajectory within the broader framework of the global energy transition. The review offers a detailed perspective on how South Africa’s coal industry, once central to its energy and economic systems, must adapt in response to the pressing need for a sustainable, low-carbon future

3. RESEARCH METHODOLOGY

3.1. Overview of Chapter 3

This chapter outlines the research methodology employed to examine the impacts of the energy transition on South Africa's coal mining sector. A mixed-methods approach was applied, focusing mainly on qualitative research supported by case studies. Semi-structured interviews were conducted with key stakeholders such as mining industry representatives, community leaders, and company executives to gather their perspectives. In addition, case studies of three major coal companies were analysed to understand the effects of policy changes, company strategies, and community experiences. These methods allowed the study to explore economic, environmental, policy, and social impacts in depth, giving a clear and well-rounded view of how the sector is responding to change.

Thematic analysis was used to identify and interpret patterns within the qualitative data, highlighting key themes such as socio-economic effects, community adaptation, and policy challenges. The research also followed strict ethical guidelines, ensuring informed consent, confidentiality, and respect for vulnerable groups most affected by the transition. Finally, the chapter discusses the study's limitations, including sample size constraints, possible bias in responses, and limits to applying the findings more broadly. Despite these challenges, the methodology provided rich insights and set a strong foundation for understanding the impacts of the energy transition on the coal mining sector.

3.2. Research Design

This section outlines the research design, data collection methods, sampling strategies, data analysis procedures, ethical considerations, limitations, and validation mechanisms. The research methodology encompasses a multidimensional approach, combining qualitative and quantitative methods to ensure a comprehensive analysis. The integration of both methods allows for a comprehensive understanding of the multifaceted impacts of the energy transition on the coal mining sector in South Africa. The following section discusses the qualitative research.

3.2.1. Qualitative Research

Interviews

Qualitative data was collected through the implementation of semi-structured interviews with key stakeholders including representatives from the coal mining industry, community leaders, and chief executive officers of coal mining companies in the eMalahleni area. The researcher employed a purposeful sampling technique to ensure that a diverse array of perspectives was represented within the study. This approach is essential to capture the breadth and depth of experiences and insights from various actors directly or indirectly affected by the energy transition.

The semi-structured interviews were guided by an interview questionnaire designed to explore a range of themes pertinent to the study's objectives. These themes include, but are not limited to, policy implications, technological adaptation, socio-economic impacts, and community perspectives. The choice of semi-structured interviews allowed for a flexible yet focused dialogue, enabling the researcher to probe deeply into specific issues while allowing interviewees the freedom to express their views and experiences comprehensively.

Policy implications were a significant focus of the interviews, examining how current and proposed policies are perceived by stakeholders and their potential impacts on the coal mining sector and the broader community. Discussions on technological adaptation explored stakeholders' views on the adoption of new technologies within the coal mining industry, assessing both the opportunities and challenges associated with such innovations.

The socio-economic impacts of the energy transition were another critical theme. Interview questions delved into how transitioning away from coal is affecting local economies, employment, and the social fabric of communities dependent on coal mining. This includes an exploration of the perceived risks and benefits of the transition, as well as the strategies being employed or proposed to mitigate adverse effects.

Community perspectives provided invaluable insights into the lived experiences of those most affected by the energy transition. This theme captured the voices of community leaders and members, highlighting their concerns, hopes, and recommendations for achieving a just transition. The inclusion of community perspectives ensured that the study remained grounded in the realities of those at the grassroots level, providing a holistic view of the transition's impacts.

Case studies

Case studies were conducted on three coal mines operated by the leading coal mining companies in South Africa. This methodological approach involved a comprehensive analysis of the effects of policy interventions, an in-depth examination of the experiences of workers and communities potentially affected by the energy transition, and a critical evaluation of the effectiveness of various transition strategies employed by these companies. By focusing on these three prominent coal mining companies the research aimed to derive detailed insights into the broader implications of the energy transition within the South African coal mining sector.

The case study analysis included a multifaceted investigation of the impacts of policy interventions on the coal mining operations. This involved assessing how different policies have influenced the operational and strategic decisions of the mining companies, the sustainability of their practices, and their overall economic performance. The examination extended to the workforce, exploring how policy changes have affected employment, job security, and working conditions within the mines. Additionally, the research delved into the socio-economic repercussions for the surrounding communities, considering factors such as local employment opportunities, economic stability, and social cohesion.

Furthermore, the case studies evaluated the transition strategies implemented by the mining companies. This encompassed an analysis of their approaches to mitigating the negative impacts of the energy transition, such as job losses and economic disruption, as well as their efforts to adapt to new technological and market realities. The effectiveness of these strategies was assessed based on various criteria, including economic viability, environmental sustainability, and social equity. By scrutinising these strategies, the research aimed to identify best practices and potential areas for improvement that can inform future policy and strategic decisions.

In parallel with the case study analysis, an extensive review and analysis of existing policies related to energy transition and coal mining in South Africa was conducted. This involved a thorough examination of policy documents, laws, and regulations to gain a comprehensive understanding of the legislative and regulatory framework governing the coal mining sector. The analysis focused on identifying the opportunities and challenges presented by these policies, evaluating their impact on the coal mining industry, and assessing their alignment with broader national and international energy transition goals.

The policy analysis also considered the political and economic factors that influence policy decisions. This included an exploration of the interests and power dynamics among key stakeholders, such as government bodies, industry associations, labour unions, and environmental groups. Understanding these factors is crucial for contextualising the policy environment and anticipating potential obstacles and enablers for the effective implementation of transition policies.

Thematic analysis

Thematic analysis is a robust qualitative research methodology employed to identify, analyse, and report patterns, or themes, within qualitative data (Naeem *et al*., 2023). This methodological approach is particularly suited for the research topic examining the effects of the energy transition on the coal sector in South Africa. By providing a structured framework, thematic analysis enabled the systematic exploration and interpretation of key themes that are embedded within the qualitative data collected from various stakeholders.

In the context of this research, thematic analysis was utilised to uncover recurrent patterns and variations within the survey results, thereby facilitating a comprehensive understanding of the complex dynamics at play. The first step in this process involved familiarisation with the data, which included transcribing interviews, reading through the data multiple times, and noting down initial observations. This immersion in the data was crucial for gaining a deep understanding of the content and context of the information provided by participants.

Subsequently, the research developed a coding framework to systematically categorises and analyses the qualitative findings. This involved generating initial codes from the data, which are the basic segments of information that appear significant or interesting. Codes were assigned to specific pieces of data that relate to the research questions and objectives. The development of the coding framework was iterative, allowing for the refinement of codes as new insights emerged during the analysis process.

Once the data was coded, the next phase involved searching for themes. Themes are broader patterns of meaning that are derived from the coded data. This step required grouping the codes into potential themes, collating all the relevant data for each potential theme, and then reviewing these themes to ensure they accurately reflected the data. This process involved both a detailed and a holistic examination of the data to identify themes that were not only recurrent but also significant in explaining the various aspects of the energy transition's impact on the coal sector.

The thematic analysis focused on themes that emerged organically from the data, which allows for the identification of issues and patterns that may not have been anticipated at the outset of the research. This inductive approach is particularly valuable for exploring the economic, environmental, policy, and community dimensions of the energy transition. For instance, themes related to economic impacts may include job losses, shifts in employment patterns, and changes in local economies. Environmental themes might encompass the reduction in pollution levels, changes in land use, and the adoption of cleaner technologies. Policy-related themes could explore the effectiveness of existing regulations, the challenges of policy implementation, and the role of government in facilitating the transition. Community themes involved the social implications of the transition, community resilience, and the responses of local populations to the changes.

By focusing on these emergent themes, the analysis provided valuable insights into the multidimensional consequences and challenges associated with transitioning away from coal in the South African context. This methodology contributed to a holistic understanding of the energy transition, highlighting not only the direct impacts on the coal sector but also the broader implications for society and the environment. Thematic analysis thus served as a powerful tool in this research, enabling a nuanced and comprehensive exploration of the complex and interconnected factors that shape the energy transition in South Africa. This section serves as a foundation for the next chapter, discussing the quantitative research.

3.2.2. Quantitative Research

The process of survey design is a critical step in gathering meaningful and representative data to address specific research questions. In this context, the survey questionnaire was crafted, drawing insights from the qualitative phase of the study. The objective was to delve into various aspects that play a pivotal role in the coal mining sector, including job security, technological adaptation, environmental concerns, and perceptions of the future.

The survey questionnaire was built upon the foundation of insights gleaned from the qualitative phase of the research. This phase involved interviews, focus group discussions, and content analysis to identify key themes and variables relevant to the coal mining industry. The survey comprehensively covered several crucial aspects to gain a holistic understanding of the coal mining workforce. Job security was explored to understand the concerns and sentiments of individuals in the industry. Technological adaptation assessed how the workforce is adjusting to technological advancements, while environmental concerns delved into the perceptions and attitudes toward sustainability and eco-friendliness. Furthermore, exploring perceptions of the future helped in anticipating trends and potential challenges.

To ensure the survey results were representative and applicable to the entire coal mining sector, stratified random sampling was employed. This method involved dividing the population into subgroups (strata) based on specific characteristics such as roles, regions, and demographics. Each stratum was then sampled independently, ensuring proportional representation. This approach helped to capture the diversity within the sector and provides insights into the nuances of different groups. By employing stratified random sampling, the survey aimed to include participants from various roles within the coal mining sector, ensuring representation from miners, supervisors, managers, and other key positions. It also considered regional differences, acknowledging that challenges and perspectives may vary across different locations. Demographic variables such as age, gender, and experience were also considered to capture a broad spectrum of perspectives.

The determination of the sample size is a crucial aspect of survey design. Statistical power calculations were employed to establish an optimal sample size that ensured the reliability and validity of the survey results. This involved considering factors such as the desired level of confidence, margin of error, and variability within the population. By calculating the sample size rigorously, the survey aimed to produce results that could be generalised to the broader coal mining workforce. The survey design incorporated a thoughtful approach, leveraging qualitative insights and employing robust sampling techniques to ensure that the data collected provided a comprehensive and accurate portrayal of the various facets of the coal mining sector.

3.3. Ethical Considerations

The investigation into the effects of the energy transition on the coal mining sector in South Africa necessitates careful ethical considerations to ensure the integrity of the research and the protection of participants' rights. This section delineates the ethical frameworks and practices adhered to throughout the study, addressing issues related to consent, confidentiality, potential biases, and the broader implications of the research findings.

Informed consent is a fundamental ethical requirement in research involving human subjects. For this study, participants including industry stakeholders, policymakers, community members, and coal sector employees were provided with detailed information regarding the purpose, procedures, potential risks, and benefits of the study prior to their involvement. Consent forms were designed to ensure that participants understood their rights, including their right to withdraw from the study at any time without penalty. The research adhered to the principles of voluntary participation, ensuring that all consent was obtained without coercion or undue influence.

Maintaining the confidentiality of participants and the secure handling of data are paramount ethical concerns. The study employed robust measures to safeguard the privacy of all respondents. Personal identifiers were removed from the data to ensure anonymity, and all data was stored securely using password-protected systems. Access to data was restricted to authorised research personnel only. Additionally, any information that could potentially identify individual respondents or specific organisations was aggregated to further protect confidentiality. The research protocol complied with relevant data protection regulations and standards, including the Protection of Personal Information Act in South Africa.

The study was designed with the intention of minimising any potential harm to participants. This includes physical, psychological, or social harm. The research protocol included measures to address any distress or discomfort participants might experience due to the sensitive nature of the study. For instance, participants were assured that their responses would not be used in a way that could jeopardise their professional reputations or personal relationships.

Ensuring transparency and maintaining the integrity of the research process are critical ethical considerations. The study adhered to principles of honesty and accuracy in reporting findings. All data collection and analysis procedures were documented to provide a clear audit trail. The research avoided selective reporting or manipulation of results. Findings were presented in a manner that accurately reflects the data and acknowledges any limitations or potential sources of bias. Additionally, any conflicts of interest were disclosed to maintain the credibility of the research.

Given that the study explored the effects of the energy transition on the coal mining sector, which has direct implications for various communities, ethical considerations also encompassed the potential impact of the research findings on these communities. The research sought to provide insights that can inform policy and practice in a way that is equitable and beneficial to affected communities. Stakeholder engagement was an integral part of the research design, ensuring that the perspectives and concerns of communities directly impacted by the coal industry were considered.

Prior to commencing the study, an ethics certificate was obtained from the University of the Witwatersrand's Ethics committee. This approval process involved a thorough review of the research design, consent procedures, data management practices, and potential risks to participants. The study was conducted in compliance with the ethical guidelines and adhered to national and international ethical standards for research involving human subjects.

The ethical considerations outlined in this chapter reflect the commitment of the research to uphold the highest standards of ethical practice. By ensuring informed consent, maintaining confidentiality, minimising harm, promoting transparency, considering community impact, and obtaining ethical approval, the study aimed to contribute valuable insights into the effects of the energy transition on South Africa's coal mining sector in a manner that respects and protects the rights and well-being of all participants involved.

3.3. Summary of Chapter 3

This chapter describes the research methodology employed in the study, detailing the approach taken to explore the effects of the energy transition on the coal mining sector in South Africa. The chapter delineates the mixed-methods approach utilised, integrating both qualitative and quantitative research techniques to provide a robust and nuanced analysis of the subject matter.

The chapter begins by outlining the mixed-methods approach, which combines qualitative and quantitative methodologies to address the multifaceted nature of the research questions. This integrative strategy allows for the triangulation of data, enhancing the reliability and depth of the findings. By employing both qualitative and quantitative methods, the study captured a comprehensive understanding of the impacts of the energy transition, offering a more complete and nuanced perspective on the issue.

In the section on qualitative research methods, the chapter details the use of in-depth, semi-structured interviews with key stakeholders, including representatives from the coal mining industry, community leaders, and chief executive officers of coal mining companies in the eMalahleni area. The purposeful sampling technique employed ensured that a diverse range of perspectives were represented, enabling the collection of rich, detailed data on themes such as policy implications, technological adaptation, socio-economic impacts, and community perspectives. The chapter also discusses the case study approach, which involved an in-depth examination of three leading coal mining companies. This method provided contextualised insights into the effects of policy interventions, the experiences of affected workers and communities, and the effectiveness of transition strategies.

The thematic analysis section of the chapter outlines the methodology used to identify, analyse, and report patterns within the qualitative data. This structured approach allowed for the systematic extraction of key themes, providing a comprehensive understanding of the economic, environmental, policy, and community dimensions of the energy transition. By focusing on emergent themes, thematic analysis facilitated a detailed exploration of the impacts and challenges associated with transitioning away from coal.

In discussing the quantitative research methods, the chapter emphasises the design and administration of surveys to collect data from a broader population within the coal mining sector and affected communities. The survey design included both closed and open-ended questions to capture a range of data, enabling the identification of trends, correlations, and general patterns. This quantitative data complemented the qualitative findings, providing a broader statistical perspective on the research topic.

The chapter also addressed the ethical considerations inherent in the research, highlighting the importance of maintaining confidentiality, anonymity, and informed consent. The study adhered to ethical guidelines to ensure the integrity and responsibility of the research process, particularly when working with vulnerable populations.

Overall, this chapter provides a detailed and methodologically rigorous framework for understanding the impacts of the energy transition on the coal mining sector in South Africa. The integration of qualitative and quantitative methods, coupled with a thorough analysis of thematic and survey data, ensures a comprehensive and nuanced exploration of the research topic.

4. RESULTS AND ANALYSIS

4.1. Overview of Chapter 4

This chapter provides an analysis of the survey results, incorporating data from both the miner's survey and the community members survey, as attached in Appendices A and B, respectively. The survey targeted 30 miners and successfully achieved this target, with all 30 participants completing the questionnaire. For the community members, the target was six participants, of which five were successfully interviewed. In the case of senior management, five interviews were targeted, and three were conducted. The responses are structured in six distinct themes, allowing for a comprehensive understanding of the recurring patterns and insights. The thematic analysis includes the following themes:

1. Awareness and understanding of the energy transition: responses related to miners' and community members knowledge of the energy transition are discussed, including their knowledge of renewable energy sources and the reasons behind the shift from traditional energy sources.
2. Economic impact and employment concerns: concerns about job security and coal demand are summarised.
3. Government and policy support: perceptions of government efforts and initiatives for the energy transition, including the effectiveness of existing policies and the need for new regulations or incentives are highlighted.
4. Health, safety and environment concerns: This theme focuses on the health and safety of miners and community members, as well as the environmental impact of the energy transition, such as pollution levels and ecological sustainability.
5. Social and community implications: This theme explores the broader social effects of the energy transition on communities, including changes in social dynamics, community cohesion, and the overall quality of life.
6. Future employment prospects and willingness to transition: This theme assesses the future job opportunities available to miners' and community members, as well as their willingness to adapt to new roles and industries as part of the energy transition.

In addition to the thematic analysis, the chapter delved into the perspectives of senior managers from the three coal mining companies with interviews from questions attached in Appendix C. Their feedback, coupled with information from their annual reports and environment, social and governance reports, offered a managerial viewpoint, enriching the overall analysis with insights from leadership and the companies' standpoint. The chapter concludes with a summary.

4.2. Results From Community Members and Miner's Questionnaires

This section provides a detailed analysis of how the energy transition affects miners and community members in the South African coal mining sector. Using data from surveys, it explored their views, worries, and experiences. By looking at key themes, the section gives a clear understanding of the challenges and opportunities that come with transitioning from fossil fuels to renewable energy.

4.2.1. Awareness and understanding of the energy transition

The responses indicate varying levels of awareness and understanding of the energy transition among miners and community members. Most participants demonstrated a basic knowledge of renewable energy sources such as solar, wind, and hydropower. They also recognised that the transition is driven by environmental concerns, climate change mitigation, and the global shift away from fossil fuels. While miners generally showed a higher awareness due to their exposure to industry developments, community members displayed more limited understanding, often associating the transition primarily with job losses or changes in electricity generation. Overall, the findings suggest that while awareness exists, there is a need for broader education on both the benefits and implications of the energy transition. Figure 9 shows the level of awareness and understanding of the miners and community members on the energy transition.

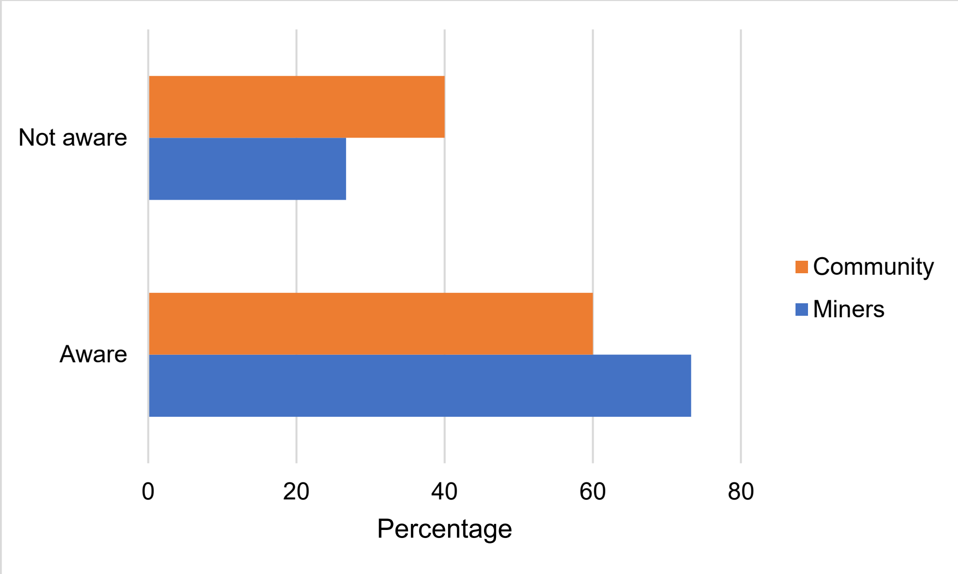

Figure 9: Awareness and understanding of the energy transition

Miners' awareness

A significant majority of miners (73.3%) are aware of the energy transition, indicating a strong understanding of the shift from fossil fuels to renewable energy sources. This awareness is crucial as it suggests that miners are cognisant of the broader changes occurring in the energy sector. The high level of awareness among miners could be attributed to increased public discourse on renewable energy and environmental sustainability, particularly in their regions which are reliant on coal. This awareness can facilitate smoother transitions within coal-dependent areas, as knowledgeable miners may be more adaptable to new policies or programmes aimed at integrating renewable energy sources into the economy.

However, 26.7% of miners are not familiar with the concept of the energy transition. This lack of awareness highlights a gap in knowledge that may hinder some miners' ability to understand or adapt to changes brought about by the transition. Addressing this gap is essential to ensure that all workers, particularly those directly impacted by shifts in the coal sector, have a comprehensive understanding of the energy transition. Targeted educational initiatives, such as information sessions, community workshops, and training programmes, can better inform miners about the implications of the energy transition, as well as the opportunities and challenges it presents.

Community Members' Awareness

Most community members are somewhat familiar with the concept of the energy transition and believe it will impact the South African coal mining industry. This familiarity suggests that the community is engaged with the ongoing changes in the energy sector and recognises the potential implications for the local economy and employment. The community's awareness can play a pivotal role in supporting the transition by fostering a collective understanding of the need for sustainable energy practices and the benefits of reducing reliance on fossil fuels.

4.2.2. Economic impact and employment concerns

The energy transition is expected to exert substantial economic pressure on South Africa’s coal mining sector. Coal mining is a significant source of employment, particularly in Mpumalanga, where the industry accounts for roughly 42% of the local economy. The gradual decommissioning of coal-fired power plants is likely to result in the loss of tens of thousands of direct mining jobs, with the broader effect of reducing incomes for dependent households and increasing unemployment in mining regions. Government revenues derived from coal-related taxes and royalties are also projected to decline, potentially constraining public spending and investment in local services. Although the renewable energy sector is anticipated to generate approximately 250 000 new jobs by 2047, these positions may not match the stability, wages, or skill requirements of traditional coal-sector employment, creating a mismatch between workforce needs and available opportunities. Regions heavily dependent on coal, are particularly vulnerable, as reduced mining activity can trigger broader economic downturns affecting local businesses and service provision. Overall, these findings highlight the dual economic and social challenges posed by the transition, emphasising the need for targeted policies in workforce retraining, regional diversification, and social support to ensure a just transition. Figure 10 assessed the economic effects of the energy transition on the community and miners, focusing on concerns about job losses, changes in income, and overall economic stability.

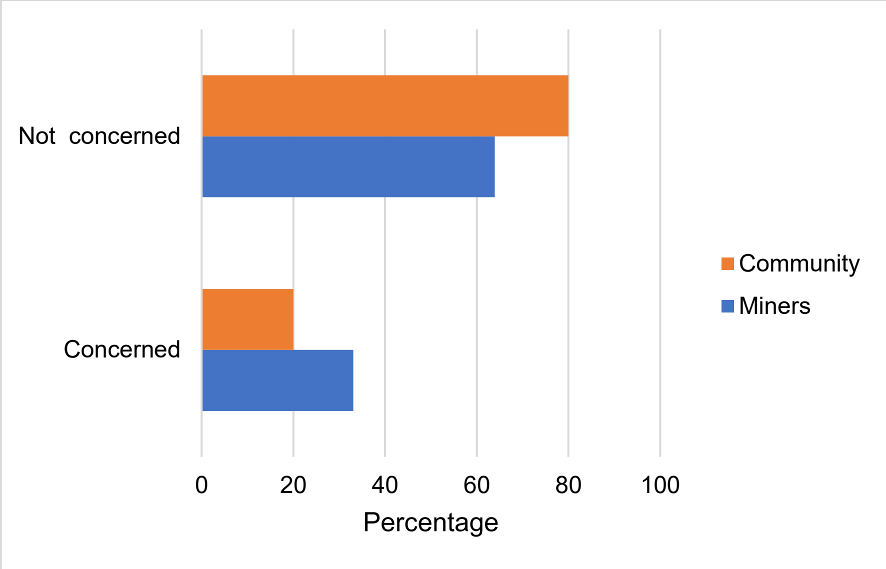

Figure 10: Economic impact and employment concerns

Miners’ economic concerns

The reference questions that contributed to this theme are Questions 3 and 4 of the miners' questionnaire, presented in Appendix A. The questions collectively provide insight into the economic impact of the energy transition on the coal mining sector. Most of the miners (57.1%) have noticed a decline in coal demand, reflected in their reduced production targets. This reflects broader global shifts towards cleaner energy sources and reduced reliance on fossil fuels. This decline in demand can have significant implications for the coal mining sector, including potential job losses, economic challenges for coal-dependent communities, and increased pressure on the industry to adapt to the ongoing energy transition. Despite these concerns, most miners (76.7%) have not yet experienced reductions in working hours or wages, suggesting that the coal mining sector has managed to maintain consistent employment levels for a significant portion of its workforce, at least in the short term.

However, 23.3% of miners have faced reductions in working hours or wages, indicating early signs of economic strain. This subset of workers is already feeling the economic pressures of the energy transition or fluctuations in the coal market. The reduction in working hours or wages for this group points to the beginning of broader economic challenges for coal-dependent regions as the transition to renewable energy continues to gain momentum globally.

Community Members' Economic Concerns

The community members indicated that they do not personally know anyone who has lot their job as a result of the energy transition in their communities. This finding suggests that the effects of the energy transition, at least within this sample, have not yet become prominent on an individual or community level. However, the community members expressed strong concerns and discomfort that the economy of their community will be in jeopardy should job losses occur as a result of the energy transition. They emphasise the need for retraining programmes and economic diversification to mitigate these impacts. Retraining programmes can equip displaced workers with the skills needed to transition into new employment opportunities in emerging industries, such as renewable energy, construction, and technology. Economic diversification efforts can stimulate alternative livelihood opportunities and reduce the community's reliance on coal mining as a primary economic driver.

4.2.3. Government and policy support

South Africa’s evolving policy framework is increasingly geared towards managing the decline of coal through a just and orderly transition, although execution challenges remain significant. Key instruments including the IRP, the Presidential Climate Commission’s Just Transition Framework, and the 2024 Climate Change Act provide strategic direction by embedding emissions targets, worker support, and social protections. Market reforms, such as the Electricity Regulation Amendment Act and the operationalisation of the National Transmission Company, aim to accelerate grid expansion and enable competitive electricity markets, while initiatives like REIPPPP Bid Window 7 seek to scale renewable energy procurement despite transmission bottlenecks. Complementary measures, including the phased tightening of the carbon tax, exposure to the EU Carbon Border Adjustment Mechanism, and concessional financing under the Just Energy Transition Partnership, further shift incentives away from coal. However, sequencing risks (coal retirements preceding replacement capacity), state-capacity constraints, and policy-coherence gaps can undermine implementation. Overall, government support has established a clear trajectory towards reducing coal dependence, but realising equitable employment and community outcomes will depend on the pace and effectiveness of execution. Figure 11 analyses the miners and community members understanding of the level of support from government policies and initiatives for the energy transition, including the effectiveness of existing policies.

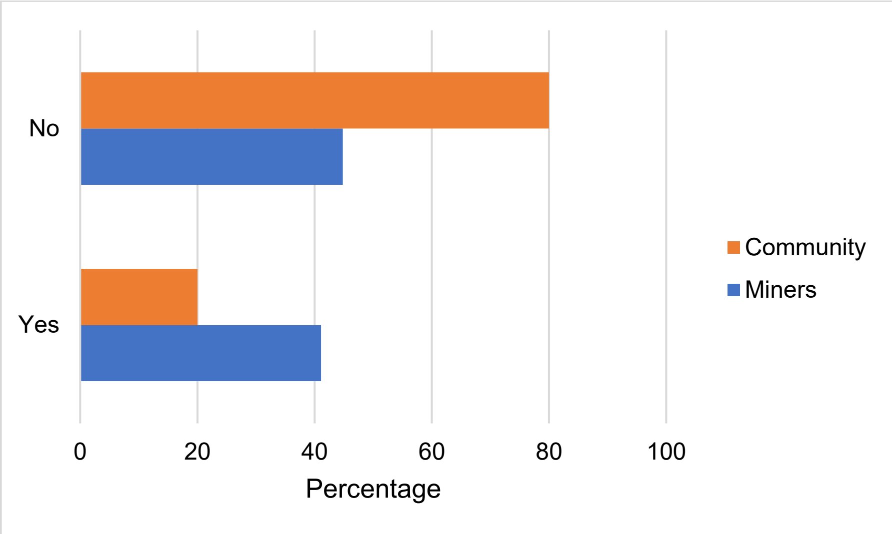

Figure 11: Government policy and support

Miners’ perspectives on government support

Opinions among miners are divided on whether the government is providing sufficient support regarding the energy transition. A plurality (44.8%) feels that the support is inadequate, reflecting a significant level of dissatisfaction or concern regarding the adequacy of governmental measures and policies in addressing the challenges faced by the coal industry during this transition period. On the contrary, 41.1% of miners believe that the government is offering adequate support, indicating that a substantial portion of the workforce perceives current government actions and interventions as effective in supporting the coal mining industry through the transition to renewable energy sources. The remaining 14.1% were undecided on the topic.

Community members perspectives on government support

Majority of the community members feel that the South African government has faced challenges in effectively communicating and implementing policies related to the energy transition. Improved transparency and collaboration with affected communities are deemed essential for a more successful and inclusive transition process. Effective communication can help manage expectations, address concerns, and foster trust between the government, coal mining companies, and local communities.

Collaborative efforts can ensure that policies are responsive to the needs and concerns of all stakeholders, thereby enhancing the likelihood of a just transition.

4.2.4. Health, safety and environmental concerns

The energy transition in South Africa’s coal mining sector has significant implications for health, safety, and environmental outcomes. Coal mining and coal-fired power plants have historically contributed to elevated levels of air pollutants, including particulate matter and greenhouse gas emissions, which are associated with respiratory illnesses and other adverse health effects in surrounding communities. As the transition progresses and coal demand declines, potential environmental improvements may emerge through reduced emissions and improved air and water quality. However, these benefits are contingent on the effective management of mine closures, as poorly rehabilitated sites can result in soil contamination, acid mine drainage, and land instability, thereby posing safety hazards for both workers and local populations. Moreover, workers transitioning from the coal sector to alternative industries may encounter new occupational risks if adequate training and safety protocols are not implemented. These dynamics underscore the importance of comprehensive planning and regulatory oversight to ensure that the energy transition yields net positive outcomes for environmental quality, worker safety, and community health. Figure 12 shows the health, safety and environmental concerns for both miners and community members.

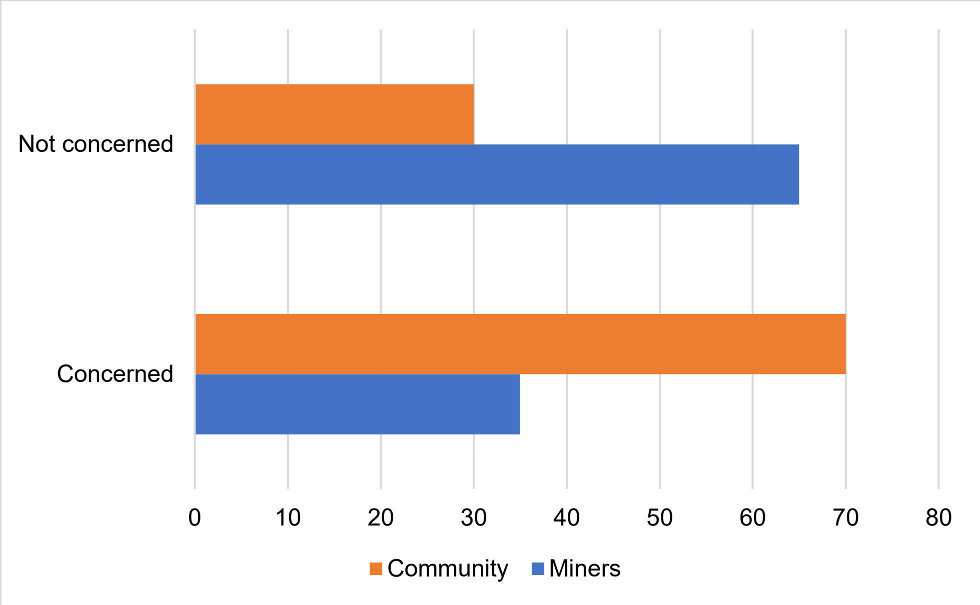

Figure 12: Health, safety and environmental concerns

Miners' health concerns

A majority of miners (73.3%) have not experienced negative health effects from working in the coal mining industry, suggesting that existing health and safety measures may be effective in mitigating potential risks. However, 23.3% of miners have reported negative health effects, highlighting the need for ongoing health and safety protocols within the industry. Continuous monitoring and enhancement of health and safety measures are essential to protect workers and address any health concerns that may arise.

A majority of miners (56.7%) believe that the energy transition will have a positive impact on the environment, reflecting a general consensus that the shift towards renewable energy sources and away from fossil fuels is expected to benefit environmental health and sustainability. This perception aligns with the broader environmental goals associated with reducing greenhouse gas emissions and mitigating climate change. However, 20% of miners disagree, indicating scepticism or concerns about the effectiveness of the transition in achieving the desired environmental outcomes.

Community members environmental concerns

Community members expressed concerns about the environmental effects of coal mining, such as air and water pollution and land degradation. These concerns underscore the importance of transitioning to cleaner energy sources to reduce the environmental impact of energy production. The adoption of renewable energy sources, such as solar, wind, and hydropower, can help mitigate these environmental issues and promote sustainable development.

Community members strongly believe that the energy transition contributes to environmental conservation by reducing greenhouse gas emissions and minimising environmental degradation. The adoption of cleaner and more sustainable energy sources, such as solar, wind, and hydropower, is seen as fundamental to reducing air pollution, mitigating climate change, and preserving natural habitats. This perspective underscores the community's support for policies and initiatives aimed at accelerating the transition to cleaner energy and highlights a collective commitment to safeguarding the environment for future generations.

4.2.5. Social and community implications

The energy transition in South Africa is projected to generate significant social and community challenges, particularly in regions with high dependence on coal mining. Reductions in mining activity are likely to contribute to elevated unemployment rates, diminished household incomes, and increased socioeconomic vulnerability. Such changes may intensify reliance on social welfare programs and place additional pressure on local services, including healthcare, education, and housing infrastructure. Moreover, communities historically reliant on coal mining may experience demographic shifts, as displaced workers migrate in search of alternative employment, potentially undermining social cohesion and established community networks. The contraction of coal-related economic activities is also expected to adversely affect small businesses and informal sector operators that serve mining communities. These considerations underscore the necessity of implementing comprehensive social support measures, community development initiatives, and inclusive transition planning to mitigate negative outcomes and promote equitable outcomes for affected

Miners' social concerns

The miners are uncertain about the implications of the energy transition. They have not yet experienced job losses as a result of the energy transition. Although they know about the energy transition, they are yet to get information from their employers on how the energy transition will affect them. Open dialogue and transparent communication between stakeholders are essential for addressing these arising social challenges and fostering mutual understanding, trust, and collaboration.

Community members' social concerns

Community members anticipate significant social challenges associated with the transition away from coal mining, including job losses, economic instability, and strains on local services. They call for comprehensive support systems to address these challenges, such as retraining and reskilling initiatives, economic diversification efforts, and social welfare provisions. These measures can help mitigate the adverse effects on the well-being of individuals and communities affected by the transition and promote resilience and adaptation amidst transformative change.

4.2.6. Future employment prospects and willingness to transition

The ongoing transition from coal to renewable energy in South Africa is anticipated to have significant implications for employment within the coal mining sector. Approximately 80,000 coal mining jobs, particularly concentrated in Mpumalanga, are at risk due to the gradual decommissioning of coal-fired power plants and the shift toward renewable energy sources (Nel, *et al*., 2023). Conversely, the renewable energy sector presents opportunities for job creation, with projections estimating the generation of between 85 000 and 250 000 new positions by 2030, primarily in energy production, agriculture, and nature-based industries (ESI Africa, 2024). The solar energy sector is expected to be a leading contributor, potentially creating up to 140 000 jobs by 2030, while the broader renewable sector can support around 500 000 green jobs by 2050, encompassing solar, wind, and bioenergy technologies (ESI Africa, 2024).

Despite these prospects, the nature of employment in the renewable energy sector may differ markedly from that in the coal sector. Renewable energy jobs are often based on short-term contracts and may lack the stability, benefits, and collective bargaining structures traditionally associated with coal mining employment. Consequently, the willingness of displaced coal workers to transition into renewable energy roles is shaped by perceptions of job security, income potential, and access to retraining programs. Regions heavily dependent on coal, such as Mpumalanga, face additional challenges due to limited local opportunities and the potential for broader socio-economic disruption. Addressing these issues requires targeted policy interventions, investment in skills development, and strategic planning to ensure a just and sustainable transition that balances environmental objectives with economic and social considerations. Figure 13 explored miners’ and community members openness to new jobs and training.

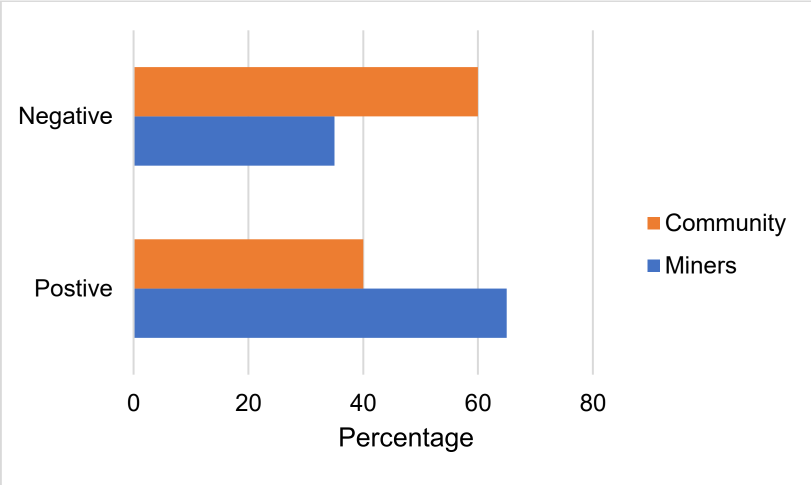

Figure 13: Future employment prospects and willingness to transition

Miners’ employment prospects

A significant majority of miners (66.7%) are concerned about the impact of the energy transition on their future employment prospects. This high level of concern indicates a pervasive sense of anxiety and uncertainty within the mining workforce about how the transition from fossil fuels to renewable energy sources might affect their job security, career trajectories, and overall employment stability within the coal mining sector. Despite these concerns, 63.3% of miners are willing to transition to different forms of employment outside the coal mining industry. This willingness to explore alternative career opportunities suggests a proactive approach to navigating potential disruptions and a recognition of the need to align with evolving industry trends.

Community members' employment concerns

Community members express scepticism about the ability to transition to renewable energy without significant economic disruption. They stress the importance of support systems and retraining programmes to facilitate smooth transitions for workers affected by the decline in coal production. Comprehensive career transition programmes, including retraining, job placement services, and career counselling, are crucial in supporting miners as they navigate potential shifts in their employment landscape and ensure they are well-equipped to adapt to changes within the energy sector.

4.2.7. Thematic correlations based on questionnaire analysis

Figure 14 presents a heatmap illustrating the correlations between key thematic areas identified in the questionnaire and central transition-related variables.

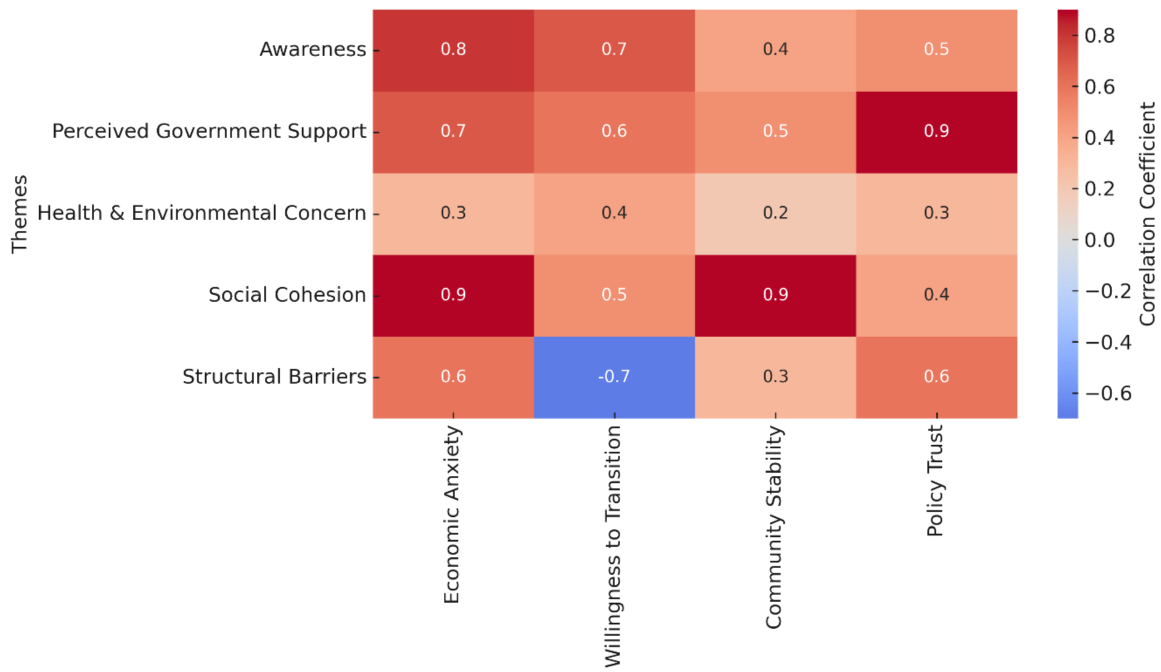

Figure 14: Thematic correlations based on questionnaire analysis

The heatmap was developed using Spearman’s rank correlation coefficient, which is well-suited for identifying monotonic relationships between ordinal variables commonly used in questionnaire data. The analysis reveals that low awareness of the energy transition is strongly correlated with high levels of economic anxiety and low willingness to transition, highlighting the role of knowledge in shaping perceptions. Similarly, perceptions of inadequate government support are closely linked to both diminished policy trust and scepticism towards future employment prospects.

Structural barriers such as age, lack of skills, and limited access to retraining show a negative correlation with willingness to transition, underlining the systemic constraints facing affected workers. The correlation between declining social cohesion and weakened community stability further illustrates the broader socio-economic risks associated with unmanaged transitions. These findings underscore the importance of integrated policy interventions that address both informational and structural challenges to support a JET.

4.3. Biodiversity loss

The coal mining sector in South Africa has historically exerted substantial pressure on local ecosystems, and the ongoing energy transition continues to influence biodiversity in complex ways. Coal mining operations, particularly open-cast mines, result in extensive habitat destruction, soil erosion, and contamination of nearby water systems through acid mine drainage and heavy metal runoff. These disturbances negatively affect both terrestrial and aquatic species, reducing population densities and altering ecosystem dynamics.

As South Africa moves toward renewable energy and reduces coal extraction, there is potential for partial ecological recovery. Abandoned mines and degraded lands can, over time, be rehabilitated through revegetation and soil restoration initiatives, providing opportunities for the return of native species. However, the rate and extent of recovery are often constrained by the severity of prior environmental damage, long-term soil contamination, and ongoing water quality issues. Additionally, the construction and expansion of renewable energy infrastructure, such as large-scale solar and wind farms, can introduce new environmental pressures. These developments require substantial land areas, which can disrupt existing habitats, fragment ecosystems, and affect migratory patterns of birds and other wildlife. Without careful site selection and ecological assessments, renewable energy projects may inadvertently contribute to biodiversity loss, even as they mitigate the environmental impacts associated with coal. Overall, the energy transition in South Africa presents a dual challenge for biodiversity: it offers the potential to alleviate some of the ecological pressures caused by coal mining while simultaneously introducing new land-use impacts. Effective environmental planning, habitat restoration, and ongoing monitoring are therefore critical to ensuring that the transition supports ecological resilience and the conservation of native biodiversity. The subsequent section discusses results from senior managers and company reports.

4.4. Results From Senior Managers and Company Reports of the Three Coal Mining Companies

Glencore, Exxaro, Seriti, Sasol, and Thungela were the top five coal producers in South Africa in 2023, ranked by production according to their annual reports. Each of these companies plays a significant role in the country's coal industry and is navigating the global energy transition with distinct strategies and priorities. This report focusses on Exxaro, Seriti, and Thungela, as they primarily produce coal and do not have significant operations in other commodities. Their approach to the energy transition is shaped by the growing global emphasis on decarbonisation and the shift toward cleaner energy sources. However, their strategies are also influenced by their operational contexts, market positions, and perspectives on the socio-economic importance of coal in South Africa. The following subsection explores how these three companies view and respond to the energy transition.

4.4.1. Exxaro Resources

Exxaro has firmly established itself as a leader in incorporating renewable energy in its portfolio in the South African mining sector by adopting a proactive approach in line with global decarbonisation objectives. The company's commitment to environmental sustainability and socio-economic equity is evident through its active investments in renewable energy, particularly via its wind energy subsidiary, Cennergi. This approach signals Exxaro's recognition of the dual imperative to reduce its carbon footprint while continuing to contribute to South Africa's energy security and economic development. A key component of this strategy is Exxaro's ambitious goal of achieving carbon neutrality by 2050, a target that aligns with international climate agreements such as the Paris Agreement, which seeks to limit global temperature rise to 1.5°C (Exxaro Resources Limited, 2023a). Exxaro has also committed to increasing its renewable energy capacity to 1.6 GW by 2030, a significant step in transitioning away from its reliance on coal, which has historically underpinned its operations (Exxaro Resources Limited, 2023b).

Exxaro’s strategy extends beyond a focus on emissions reductions, encompassing a broader, more inclusive agenda through its commitment to a "just transition." In the context of South Africa, a country heavily reliant on coal for both energy and employment, a just transition requires balancing environmental imperatives with the socio-economic well-being of communities that are dependent on the coal industry. Exxaro’s initiatives, which include the creation of alternative livelihoods, investment in skills development, and fostering new industries, are designed to minimise the socio-economic disruptions associated with decarbonisation. This holistic approach is especially critical given the role that coal mining plays in South Africa’s job market and regional economies, particularly in Mpumalanga, which is heavily reliant on the coal industry (Exxaro Resources Limited, 2023b). By prioritising social inclusivity alongside its environmental goals, Exxaro demonstrates a comprehensive understanding of the interconnected challenges posed by the energy transition.

Moreover, Exxaro’s active participation in global forums, such as the United Nations Climate Change Conference of the Parties (COP), reflects its engagement with international stakeholders and commitment to aligning its practices with global best standards in sustainability. Its adoption of the Task Force on Climate-related Financial Disclosures (TCFD) framework further underscores its commitment to transparency and accountability in managing climate-related risks. This integration of sustainability into its governance structure reflects Exxaro’s aspiration to lead by example, illustrating how mining companies can navigate the complexities of decarbonisation while maintaining financial viability and supporting broader societal goals (Exxaro Resources Limited, 2023b),

Through these initiatives, Exxaro positions itself not only as a major player in South Africa’s energy sector but also as a leader in the global push toward sustainable and inclusive growth. Its efforts demonstrate that mining companies, traditionally seen as contributors to environmental degradation, can play a crucial role in the global energy transition by investing in cleaner energy alternatives and ensuring that vulnerable communities are supported throughout the transition process.

4.4.2. Seriti Resources

Seriti, the second largest coal producers in South Africa in terms of production and a critical supplier to the state-owned utility Eskom, has taken a more measured approach to the energy transition. While Seriti acknowledges the growing importance of renewable energy within the global and national energy landscape, it maintains a significant commitment to coal. This is primarily due to coal's essential role in sustaining South Africa’s electricity grid, where coal-fired power stations provide the majority of the country's energy (Seriti Resources, 2022). South Africa, unlike many other nations, faces unique challenges in transitioning from coal due to its heavy reliance on coal-powered energy and the socio-economic implications of a rapid shift away from coal-dependent sectors.

Seriti’s strategy underscores coal as a cornerstone of energy security, recognising the risk of destabilising the country's electricity supply in the absence of adequate and reliable alternatives. Given South Africa's persistent energy shortages and load-shedding challenges, Seriti's focus on coal is both pragmatic and necessary in the short to medium term. This cautious approach allows Seriti to continue meeting the country’s immediate energy needs while gradually exploring ways to mitigate the environmental impact of its operations (Seriti Resources, 2023).

At the same time, Seriti has begun taking steps toward decarbonisation. The company has initiated renewable energy projects aimed at reducing its overall environmental footprint. In 2022, Seriti partnered with renewable energy companies to investigate the feasibility of renewable energy solutions for powering its operations and reducing its reliance on grid electricity. For instance, Seriti has explored solar energy solutions for its mining operations, demonstrating a gradual shift toward integrating cleaner energy sources into its business model (Seriti Resources, 2022). However, Seriti remains clear that coal will continue to form a central part of its portfolio for the foreseeable future, due in large part to the socio-economic risks associated with a rapid transition away from coal.

One of the most significant risks posed by a swift departure from coal is the potential economic disruption in coal-dependent regions, particularly in provinces like

Mpumalanga, where coal mining supports thousands of jobs. Seriti has emphasised that a balanced transition is necessary to avoid exacerbating unemployment and economic instability in these areas (Seriti Resources, 2023). In this respect, Seriti's approach to the energy transition reflects an understanding of the broader socio-economic dynamics at play in South Africa, where energy security, employment, and economic stability are inextricably linked to the coal industry.

While Seriti is beginning to explore renewable energy and decarbonisation initiatives, coal remains central to its strategy, given its importance to South Africa's energy security and economy. The company's cautious approach reflects the challenges of balancing the need for a cleaner energy future with the socio-economic realities of a country deeply dependent on coal. Seriti's approach is emblematic of the wider energy transition challenges faced by South Africa, as it seeks to balance decarbonisation efforts with the need to sustain its energy infrastructure and protect livelihoods in coal-dependent regions.

4.4.3. Thungela Resources

Thungela, a spin-off from Anglo American, remains heavily focused on coal, particularly thermal coal for export markets. This strategic focus is rooted in South Africa's continued reliance on coal as a critical source of energy and foreign exchange, especially given the high demand for thermal coal in regions such as Asia. Thungela's operations are primarily geared towards maximising the value of its coal assets while recognising the challenges posed by the global shift towards decarbonisation (Thungela Resources, 2023a). The company has expressed concerns over the broader implications of the energy transition for coal-dependent economies like South Africa, which still rely on coal for a significant portion of energy generation and employment, especially in mining regions such as Mpumalanga (Thungela Resources, 2023a).

In the short to medium term, Thungela remains committed to coal production, with little indication that it plans to transition toward renewable energy in any significant way. This decision is driven largely by market demand and the profitability of thermal coal exports, particularly as emerging markets in Asia continue to rely on coal for power generation. However, Thungela is aware of the long-term risks associated with global decarbonisation trends, which can affect the viability of coal production in the future as international regulations and climate policies tighten (Thungela Resources, 2023a). The company has acknowledged that shifting investor sentiment and international pressure to reduce carbon emissions can have financial implications for its business, but it has yet to announce a definitive renewable energy strategy in response to these challenges (Thungela Resources, 2023a).

Instead of making substantial investments in renewable energy, Thungela is focusing on mitigating the environmental impact of its coal operations. The company has prioritised improving operational efficiency and reducing emissions at its mining sites, as well as investing in environmental rehabilitation efforts. These measures include reclaiming mined land, managing water usage, and reducing air pollution in surrounding communities (Thungela Resources, 2023a). Environmental rehabilitation is a key component of Thungela's sustainability strategy, as the company seeks to responsibly manage the lifecycle of its coal assets. By addressing the environmental footprint of its operations, Thungela aims to demonstrate that coal production can be conducted in a manner that mitigates some of the adverse impacts associated with mining (Thungela Resources, 2023b).

Thungela's current approach reflects a pragmatic strategy centred on managing its existing coal assets while preparing for the potential risks of the energy transition. Unlike some of its peers in the coal industry, Thungela has yet to embrace a diversified energy portfolio that includes renewables. Instead, the company continues to focus on operational efficiency, environmental stewardship, and the continued profitability of its coal mining business. This approach highlights the broader tension in South Africa's energy landscape, where coal remains economically vital even as the global energy transition gathers momentum.

4.5. Projected Employment and Socioeconomic Impacts of the Energy Transition on South African Coal Miners: A Scenario Analysis

This section presents an applied scenario analysis of how approximately 94 000 South African coal miners may be affected by the energy transition. The analysis integrates national policy frameworks such as the IRP, the REIPPPP the JET-IP, and the Carbon Tax Act together with international lessons from coal transition experiences in the UK, Germany, USA, China, and Denmark.

4.5.1. Assumptions

The scenario is based on the following assumptions:

- Starting workforce: 94 000 coal miners.
- Employment linkage: 80% of jobs are tied to Eskom (domestic power generation), while 20% serve export or industrial demand.
- Coal phase-down trajectory (IRP/JET-IP): 30% of coal capacity will be retired by 2030, 55–70% by 2035–2040, and 80% by 2050.
- Natural attrition: Approximately 2.5% of the workforce exits annually through retirements or voluntary turnover.
- Redeployment potential under a well-managed transition: 70% of displaced workers can be absorbed into alternative sectors (renewable energy, grid expansion, storage, transmission, mine rehabilitation, energy efficiency, and manufacturing); 20% are expected to exit through retirement or voluntary packages; and 10% face the risk of redundancy. These proportions reflect approaches observed in Germany's Coal Commission, the UK's Contract-for-Difference (CfD) system, and Denmark's negotiated transition model. Less favourable outcomes typically emerge where policy implementation is delayed.

4.5.2. Lessons from other countries

- UK: The combination of a Carbon Price Floor and long-term CfDs enabled rapid coal closures alongside significant renewable energy investment.
  Lesson: Durable price signals, combined with bankable offtake arrangements, are critical to mobilising capital for renewables and storage.

- Germany: Through the Coal Commission, Germany introduced compensation measures and place-based investment, cushioning lignite-dependent regions. *Lesson:* A negotiated social compact anchored in retraining, regional diversification, and legal guarantees should be prioritised early.
- USA: The Inflation Reduction Act (IRA) and state-level Renewable Portfolio Standards (RPS) supported large-scale renewable deployment. However, coal-dependent regions required targeted assistance.
  Lesson: National incentives must be complemented by local content rules and community benefit clauses to ensure just outcomes.
- China: National targets were combined with provincial-level caps and industrial policy measures.
  Lesson: Provinces such as Mpumalanga need tailored transition envelopes and industrial policy tools to manage coal dependence.
- Denmark: Long-term cross-party agreements facilitated investment in offshore wind and grid infrastructure.
  Lesson: Consensus-based policy, grid expansion, and port/rail upgrades help direct jobs into regions where coal declines.

4.5.3. Managed Transition Scenario (policy on track)

To quantify potential labour market outcomes, employment impacts were modelled against Eskom-linked coal demand and adjusted for natural attrition. Table 4 presents the managed transition scenario for approximately 94 000 coal miners.

Table 4: Managed transition scenario for South African coal miners

Milestone	Coal retire (Eskom)	Jobs "at risk" from retirements (subset of Eskom-linked 75,200)	Attrition offset (same period)	Needing action after attrition	Redeployed (70%)	Retire/voluntary (20%)	Redundancy (10%)
2025 - 2030	30%	22 560	8 960	13 600	9 520	2 720	1 360
2030 - 2035	55% (extra 25%)	18 800	7 840	10 960	7 672	2 192	1 096
2035 - 2040	70% (extra 15%)	11 280	6 891	4 389	3 072	878	439
2040 - 2050	80% (extra 10%)	7 520	11 521	0 (attrition covers)	—	—	—

Cumulatively, between 2025 and 2040, a well-managed transition can result in the redeployment of approximately 20 264 miners, with 5 790 exiting through retirement or voluntary departure, and 2 895 experiencing redundancy. From 2040 to 2050, natural attrition is expected to fully absorb the remaining 10% reduction in coal demand, eliminating the need for forced layoffs if planning remains consistent. The key implication is that, with steady project implementation and robust social support, over 85–90% of the workforce impacts up to 2040 can be managed through redeployment and voluntary exits, while involuntary job losses can be limited to around 3% of the original workforce.

Redeployment Pathways

Potential redeployment opportunities span multiple sectors proven effective in international transitions:

- Electricity transmission and distribution: line work, substations, grid operations, and utility-scale storage.
- Renewable energy construction and operations: especially in wind and solar projects, where construction generates most of short-term job-years and operations secure longer-term positions.
- Mine rehabilitation and land repurposing: including acid mine drainage treatment, slope stabilisation, reforestation, and agri-solar initiatives, drawing lessons from Germany.

- Regional industrial diversification: manufacturing renewable components, repurposing brownfield sites, and piloting green fuel projects, as undertaken in the UK, Germany, and Denmark.
- Energy efficiency and public works programmes: building retrofits, municipal energy management, and similar initiatives, which have created rapid employment gains in the United States.

4.6. Summary of Chapter 4

The survey results offer a comprehensive overview of the energy transition's impact on South Africa's coal mining sector, highlighting key areas of transformation, such as employment dynamics, economic implications, environmental concerns, and community perspectives. The thematic analysis of the miner and community survey responses highlights key concerns and perceptions surrounding the energy transition. Awareness and understanding of the transition are relatively high among miners but less comprehensive among community members. Economic and employment concerns are prominent, with miners observing a decline in coal demand, though most have not yet faced wage or job reductions. Government and policy support is viewed as inadequate by many, with concerns over unclear policies and limited transition assistance. Labour conditions and future employment prospects reveal that while most miners are willing to transition to new jobs, most have not received training or support. Health, safety, and environmental concerns highlight mixed views, with some miners reporting health issues and community members expressing concerns about pollution. Social and community implications show that job uncertainty is straining relationships between mining companies and communities, though many community members do not yet see direct impacts. Overall, while there is recognition of the long-term effects of the energy transition, concerns about economic stability, government intervention, and the pace of change remain significant.

When examining the responses of major coal companies like Exxaro, Seriti, and Thungela, their respective strategies further emphasise the complexity of this transition. Exxaro has adopted a proactive approach by investing in renewable energy through its subsidiary, Cennergi, while maintaining coal production. The company emphasises a "just transition" to minimise socio-economic disruptions and ensure community welfare, underscoring its commitment to carbon neutrality by 2050. Seriti, on the other hand, takes a more cautious stance, continuing to prioritise coal to meet South Africa’s energy demands, though it is exploring decarbonisation initiatives. Seriti's approach is primarily focused on maintaining coal as a vital component of energy security while mitigating environmental impacts through improved operational efficiency. Lastly, Thungela remains firmly committed to coal, particularly for export markets, but acknowledges the long-term risks associated with global decarbonisation. While it has yet to make significant investments in renewable energy, Thungela is focused on improving the environmental sustainability of its operations through land rehabilitation and efficiency measures.

These different approaches reflect the broader challenges and opportunities identified in the survey, particularly in terms of employment shifts. The transition is causing significant job losses in coal-dependent regions, but it also offers potential for new employment in renewable energy industries, though this will require extensive retraining and reskilling programmes. Economically, the transition affects coal prices and market demand, pushing companies and governments to explore strategies for economic diversification. Environmentally, reducing coal reliance is critical for addressing climate change, as highlighted by the survey’s findings, yet it also demands comprehensive policies to manage the negative externalities of coal mining and ensure sustainable practices.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Overview of Chapter 5

This chapter synthesises the key findings of the research on the effects of the energy transition on the coal mining sector in South Africa, highlighting both the challenges and opportunities that arise from this transition. It reflects on the broader implications of transitioning away from coal, considering economic, social, and environmental dimensions, and provides strategic recommendations for navigating this transition in a just and sustainable manner. The conclusions underscore the dual pressures facing South Africa. On one hand, the country is committed to reducing carbon emissions in alignment with global climate targets, necessitating a shift away from coal as a primary energy source. On the other hand, coal remains a cornerstone of South Africa's energy system and economic framework, supporting thousands of jobs and contributing significantly to GDP and energy security. This tension between environmental imperatives and socio-economic realities presents a complex policy and operational challenge that requires a carefully managed transition.

The chapter also explores the broader consequences of a declining coal sector, including potential job losses, regional economic disruptions, and energy security concerns. It examines how communities, workers, and businesses dependent on coal can be supported through targeted policy interventions, investment in alternative energy industries, and workforce reskilling initiatives. In response to these challenges, the recommendations focus on balancing sustainability with economic resilience. They emphasise the need for a phased and inclusive transition strategy that prioritises social equity, economic diversification, and investment in renewable energy infrastructure. Policy recommendations also highlight the importance of public-private partnership, social dialogue with affected communities, and financial mechanisms to facilitate a just transition. The next section discusses limitations of the findings.

5.2. Conclusions

The transition to renewable energy is recognised as a global imperative, primarily driven by the need to reduce greenhouse gas emissions and mitigate the severe impacts of climate change. Countries worldwide, including South Africa, are under increasing pressure to shift from fossil fuels to cleaner, more sustainable energy sources like solar, wind, and hydroelectric power. However, this shift is particularly complex for nations like South Africa, where coal plays a crucial role not only in energy production but also in the economy and employment.

South Africa is the largest producer of coal in Africa and one of the top coal exporters globally. The country's reliance on coal has provided affordable energy to support industrial growth and development. However, the negative environmental impacts, including significant contributions to carbon emissions and local environmental degradation, have become increasingly unsustainable in the context of global climate change objectives.

The findings indicate that existing energy policies and regulatory frameworks are playing a significant role in driving South Africa's transition towards a low-carbon future, with increasing pressure to phase out coal in favour of renewable energy sources. The South African government has made commitments to reduce emissions and promote cleaner energy alternatives, signalling a shift in the country's energy strategy. However, the regulatory landscape remains fragmented, with overlapping policies, inconsistent enforcement, and a lack of coordinated efforts between various levels of government. These challenges hinder the effective implementation of energy policies and make it difficult to align them with broader economic and social considerations, such as job preservation, energy security, and regional development. To achieve a smooth transition, South Africa needs a more integrated and cohesive regulatory framework that balances environmental goals with the socio-economic needs of communities and industries reliant on coal.

Economically, the energy transition presents both substantial risks and promising opportunities for South Africa. The decline of coal as a primary energy source threatens jobs in the coal sector, reduces its contribution to GDP, and risks destabilising regional economies that are heavily dependent on coal mining and coal-fired power plants. However, the shift to renewable energy sources opens new avenues for investment in industries such as solar, wind, and energy storage, which can drive infrastructure development and generate employment in emerging sectors.

Additionally, there are opportunities for economic diversification, with the potential to attract green investments and foster innovation in clean technologies.

The environmental assessment confirms that transitioning away from coal can reduce carbon emissions and mitigate climate change effects. South Africa's heavy reliance on coal has contributed to environmental degradation, and shifting to cleaner energy sources offers long-term benefits, including improved air quality, water conservation, and enhanced sustainability. However, the transition away from coal presents several challenges that must be carefully managed to ensure environmental and economic stability. Renewable energy sources offer considerable environmental benefits but also involve ecological impacts, such as land use concerns and resource-intensive manufacturing processes. Additionally, the decommissioning of coal mines and coal-fired power plants has led to efforts to restore ecosystems, address water contamination issues, and prevent former mining sites from becoming abandoned wastelands. The transition to a more sustainable future involves balancing environmental protection with economic resilience, as South Africa moves away from coal reliance. The coal sector has historically played a crucial role in South Africa's industrial development, and its deep integration into the energy system means that moving towards alternative sources requires substantial investment, infrastructure development, and policy alignment.

In terms of technological advancements, the study reveals that innovations in renewable energy, energy storage, and cleaner technologies present viable alternatives to coal-dependent energy systems, offering the potential for a more sustainable and diversified energy mix. Advances in solar and wind energy, along with improvements in battery storage, have made renewable sources more reliable and cost-effective, reducing dependence on coal-fired power generation. Additionally, emerging technologies such as CCS and green hydrogen production offer promising solutions to mitigate emissions while maintaining energy security. However, the transition to these alternatives requires substantial investment in infrastructure, including the expansion of renewable energy grids, the modernisation of transmission and distribution networks, and the establishment of energy storage facilities to ensure stability and efficiency. Equally important is the need for targeted skills development programmes to equip workers with the expertise needed for jobs in the renewable energy sector, preventing large-scale unemployment due to the decline of coal-related industries. Supportive policies, regulatory incentives, and financial mechanisms must also be in place to encourage private sector investment, drive technological innovation, and create an enabling environment for the large-scale adoption of cleaner energy solutions. Without a coordinated approach that integrates technological progress with economic and workforce planning, the transition risks being slow, costly, and socially disruptive, highlighting the need for strategic, long-term policymaking.

The social dimension of the transition remains one of the most pressing concerns, particularly for communities and individuals whose livelihoods depend on the coal mining sector. The research highlights the risks of job displacement and economic hardship, emphasising the need for well-structured retraining programmes, social safety nets, and community-driven development initiatives to ensure an equitable transition.

A comparative analysis with other countries that have undergone similar energy transitions provides valuable insights into how South Africa might navigate its own shift away from coal. Case studies from countries such as Germany, UK, USA, China, and Denmark, which have successfully managed their transitions to cleaner energy, highlight the importance of a coordinated, multi-stakeholder approach. These transitions were not solely driven by government policies, but also involved active participation from the private sector, civil society, and affected communities. Successful transitions involved clear, long-term planning with strong governmental support, including financial incentives, regulatory frameworks, and investment in research and development for clean technologies. Additionally, collaboration with the private sector ensured the mobilisation of necessary resources and innovations, while social engagement facilitated the development of retraining programmes and safety nets for workers impacted by the decline of traditional industries. These case studies suggest that balancing economic growth with environmental sustainability requires a holistic approach that considers the interests of all stakeholders, ensuring that the transition is inclusive and equitable, providing opportunities for economic diversification, and mitigating social disruption. By learning from the experiences of these regions, South Africa can develop a more effective strategy that aligns with both its energy goals and its socio-economic realities. The subsequent section discusses recommendations.

5.3. Limitations of the Findings

The research is subject to several limitations that warrant consideration. Acknowledging these limitations is crucial for contextualising the study's findings and for guiding future research directions. Firstly, the research’s dependence on survey data introduces inherent biases associated with self-reporting. Respondents comprising industry stakeholders, policymakers, and community members may provide answers influenced by their personal or professional perspectives. Such biases maybe distorted the accuracy of the data and affect the reliability of the findings. For instance, industry stakeholders may have presented an overly optimistic view of the energy transition’s impact on employment and economic stability, whereas community members may have emphasised negative aspects such as job losses or environmental degradation. Moreover, the representativeness of the sample is another concern. Regional disparities within South Africa and variations in the coal mining sector may result in a sample that did not fully capture the diversity of experiences and impacts across different areas and operational levels. This limitation affects the generalisability of the study's conclusions to the entire industry.

In addition, while the study acknowledges the importance of engaging a broader range of stakeholders such as government officials, energy policy experts, academic researchers, trade unions, and environmental advocacy groups, primary engagement with these groups through interviews or workshops was not undertaken. Instead, their perspectives were incorporated indirectly through the review of secondary sources, including policy documents, industry reports, labour union statements, environmental NGO publications, and media coverage. While this approach allowed for a breadth of viewpoints within the available scope and resources, it is recognised that direct engagement with the stakeholders could have provided deeper, context-specific insights and further validated the conclusions of this study.

Secondly, the temporal scope of the study poses a constraint on its analytical depth. The energy transition is an evolving process characterised by continuous changes in policy, technology, and market conditions. The snapshot provided by the survey data reflects the state of affairs at a particular point in time and may not account for future developments or the long-term consequences of the transition. As new policies are enacted and technological advancements emerge, the effects on the coal mining sector may shift, necessitating a longitudinal perspective to fully understand these dynamic changes.

Additionally, the broad nature of the survey's focus on employment, economic, environmental, and community impacts may lead to a lack of depth in understanding the specific mechanisms driving these changes. The energy transition involves a complex interplay of factors, including technological innovations, regulatory frameworks, and market fluctuations. The survey's generalised approach may overlook intricate details and nuanced interactions among these factors, limiting the comprehensiveness of the analysis.

Lastly, the study's ability to address the diverse experiences within the coal mining sector is limited. The sector comprises various sub sectors and operational levels, each potentially experiencing the transition in unique ways. The aggregated data may have masked these differences, thereby limiting the ability to draw specific conclusions about particular sub sectors or operational contexts. While the study offers valuable insights into the effects of the energy transition on South Africa's coal mining sector, these limitations should be carefully considered. Future research should aim to address these shortcomings by incorporating longitudinal data, enhancing sample representativeness, and exploring sector-specific impacts in greater detail. Such efforts will contribute to a more nuanced and comprehensive understanding of the ongoing transformation within the coal mining industry.

5.4. Recommendations

The transition to a more sustainable energy future requires a comprehensive and strategic approach that addresses both local and global challenges. It is essential to ensure that communities currently dependent on coal are supported throughout the process, with mechanisms in place to facilitate a smooth shift towards cleaner energy sources. Investment in renewable energy infrastructure is a key element of this transition, ensuring long-term sustainability and reducing dependency on fossil fuels. Additionally, funding must be managed responsibly, with a focus on conditional support to ensure efficiency and accountability. As the shift unfolds, maintaining energy security is crucial to prevent disruptions, while international collaboration will be vital in fostering shared knowledge, resources, and strategies to meet common energy goals.

The study emphasises that proactive economic planning and well-thought-out investment strategies are essential to minimise the adverse effects of coal's decline, while ensuring that the benefits of the energy transition, such as job creation and economic growth in new sectors, are maximised. Effective strategies must include workforce retraining, regional economic support, and policy incentives to ensure a just and sustainable transition. The following sections explore these strategies in greater detail.

5.4.1. Phased transition with support for coal communities

A phased approach to South Africa's energy transition is essential to minimise the socio-economic disruption that can result from a rapid shift away from coal. The coal sector provides direct employment to approximately 94 531 people and supports hundreds of thousands more in related industries (Minerals Council South Africa, 2023). A sudden move to renewable energy without adequate planning will likely lead to widespread job losses, deepening poverty and inequality in coal-dependent regions. Therefore, the South African government must implement policies that facilitate a "just transition" by gradually reducing coal reliance while creating new opportunities for coal workers.

Retraining programmes and economic diversification initiatives are crucial in supporting the workforce during the transition. These programmes should be designed to equip workers with skills relevant to the renewable energy sector, such as solar panel installation, wind turbine maintenance, and energy storage management (Burton *et al*., 2019). For example, Germany's Ruhr Valley offers a useful case study, where coal workers were retrained in technology and service sectors as the region transitioned away from coal (Oei *et al*., 2020). South Africa should follow similar practices, ensuring that retraining programmes are locally tailored and accessible to communities affected by the energy transition.

5.4.2. Investment in renewable energy infrastructure

To meet both national and global energy demands, South Africa needs to significantly increase its investment in renewable energy infrastructure. The country has one of the highest solar potentials in the world, receiving more than 2,500 hours of sunshine annually, and has considerable wind energy potential (Fluri, 2009). Leveraging these natural resources is crucial to reducing dependence on coal while ensuring the energy needs of the country are met. However, delays in renewable energy project completion, coupled with the intermittent nature of renewable sources, pose challenges.

The South African government should accelerate the development of renewable energy projects, such as solar and wind farms, and ensure that these projects are completed on time. Investment should also focus on enhancing energy storage technologies, as these are essential for stabilising the electricity grid when renewable energy sources are inconsistent. International funding from the $8.5 billion pledged by the Just Energy Transition Partnership, together with the additional $3.5 billion and $1 billion should be directed toward research and development in energy efficiency and storage. This will allow South Africa to reduce its carbon footprint while improving the reliability of its energy supply. For example, investment in battery storage technology can mitigate the intermittency issues associated with solar and wind energy.

5.4.3. Conditional funding utilisation

The international funding granted to South Africa as part of its energy transition must be used transparently and efficiently to ensure the country meets both its climate and socio-economic goals. The conditions attached to this funding, which include reducing reliance on coal and promoting renewable energy infrastructure, require careful management to ensure that the socio-economic impacts on coal-dependent communities are mitigated. A comprehensive monitoring and evaluation framework is critical for tracking the progress and impact of this funding. To ensure transparency, South Africa should establish independent oversight bodies tasked with monitoring the allocation and utilisation of the funds. This will not only promote accountability but also ensure that funds are distributed equitably, with a focus on supporting both energy infrastructure development and economic resilience in affected regions. Additionally, community engagement is vital; affected coal-reliant communities should be involved in decision-making processes to ensure that their needs are met during the transition (Newell & Mulvaney, 2013).

5.4.4. Energy security considerations

Ensuring energy security during the transition from coal to renewable energy is paramount for South Africa. Global energy markets remain volatile, as demonstrated by recent geopolitical tensions, including the war in Ukraine, which disrupted energy supplies and caused fluctuations in prices of oil, natural gas and electricity in several countries (International Renewable Energy Agency, 2022). South Africa must plan for similar risks by incorporating energy storage solutions and improving electricity grid stability as it transitions to renewable energy.

The premature phasing-out of coal could lead to power shortages if renewable energy sources do not fully meet the country's energy demands. Lessons can be learned from countries like UK, which, despite its commitment to decarbonisation, had to temporarily revert to coal-fired power generation during energy supply challenges in 2022, largely due to the impact of natural gas shortages from geopolitical issues. However, UK is still on track to fully phase out coal by 2024, with a heavy emphasis on renewable energy, nuclear power, and storage systems to ensure energy security. Therefore, South Africa should incorporate backup systems such as battery storage and invest in technologies that allow for the efficient integration of renewable energy into the national grid. Additionally, maintaining some coal-fired power plants as backup during the early stages of the transition may help to safeguard energy security.

5.4.5. International collaboration and adaptation

South Africa should engage in international collaboration to share knowledge and experiences regarding energy transitions. Countries that have undergone or are undergoing similar transitions, such as Germany and UK, offer valuable lessons in managing socio-economic impacts, energy security, and decarbonisation efforts. Collaborative efforts with these countries will enable South Africa to adopt best practices and avoid common pitfalls associated with transitioning away from coal (Oei *et al*., 2020).

Moreover, South Africa should advocate for more flexible timelines and conditions within its international funding agreements, especially those related to its Just Energy Transition Partnership. The socio-economic realities of transitioning from coal in a developing country are different from those in wealthier nations. Therefore, global agreements should consider the unique challenges faced by countries like South Africa and allow for more adaptive and context-specific strategies to ensure that the energy transition is both sustainable and equitable (Newell & Mulvaney, 2013).

5.4.6. Recommendations for future research

Future research should focus on engaging a broader range of stakeholders including government officials, energy policy experts, academic researchers, trade unions, and environmental advocacy groups in order to capture diverse perspectives on the energy transition. In this study, such primary engagement through interviews or workshops was not undertaken; rather, stakeholder perspectives were incorporated indirectly through secondary sources such as policy documents, industry reports, union statements, environmental NGO publications, and media coverage. Moving forward, research should prioritise localised case studies to understand how coal-dependent communities adapt to the transition, as well as longitudinal assessments that track social, economic, and environmental impacts over time. Comparative analyses across regions or countries would help identify transferable lessons and best practices, while further examination of alternative economic pathways, community-led initiatives, and financial mechanisms such as carbon taxes and green bonds could provide valuable insights into sustainable strategies for coal regions. Addressing these gaps would contribute to a more comprehensive understanding of the transition and better inform policies that support a just, equitable, and sustainable energy future.

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Appendix A: Survey questionnaire for miners

1. Do you know what the energy transition is?
   - Yes
   - No
   - Maybe

2. Have you worked in the coal mining sector in South Africa for more than 2 years?
   - Yes
   - No
   - Maybe

3. Have you noticed a decline in demand for coal in the past year?
   - Yes
   - No
   - Maybe

4. Have you experienced a reduction in working hours or wages in the past year?
   - Yes
   - No
   - Maybe

5. Do you believe that the energy transition will lead to a decline in the coal mining industry in South Africa?
   - Yes
   - No
   - Maybe

6. Have you received any training or support to transition to other forms of employment?
   - Yes
   - No
   - Maybe

7. Do you feel that the government is doing enough to support the coal mining sector during the energy transition?
   - Yes

- No
- Maybe

8. Are you concerned about the impact of the energy transition on your future employment prospects?
   - Yes
   - No
   - Maybe

9. Would you be willing to transition to a different form of employment outside of the coal mining industry?
   - Yes
   - No
   - Maybe

10. Have you experienced any negative health effects because of working in the coal mining industry?
    - Yes
    - No
    - Maybe

11. Do you believe that the energy transition will have a positive impact on the environment?
    - Yes
    - No
    - Maybe

Appendix B: Survey questionnaire for community members

1. **Demographic Information:** a. What is your age range?
    - o 18-24
    - o 25-34
    - o 35-44
    - o 45-54
    - o 55 and above

b. what is your gender?

- o Male
- o Female
- o Non-binary
- o Prefer not to say

c. In which Province in South Africa do you reside?

- o Limpopo
- o Gauteng
- o Mpumalanga
- o North-West

2. **Awareness and Perception:** a. How familiar are you with the concept of the energy transition?
    - o Very familiar
    - o Somewhat familiar
    - o Not familiar at all

b. Do you believe the energy transition will have an impact on the South African coal mining sector?

- o Strongly Agree
- o Agree
- o Neutral
- o Disagree
- o Strongly disagree

3. **Economic Impact:** a. From your perspective, how has the energy transition affected employment in the South African coal mining sector?

b. Do you think there are potential economic opportunities in other industries for those currently employed in the coal mining sector?

- Yes
- No

4. **Environmental Impact:** a. To what extent do you believe the energy transition contributes to environmental conservation?

b. Are you concerned about the environmental effects of coal mining in South Africa? (e.g. air and water pollution, land degradation)

- Yes
- No

5. **Community and Social Implications:** a. How has the energy transition influenced the relationship between coal mining companies and local communities?

b. What role do you think the government should play in supporting communities affected by the changes in the coal mining sector?

6. **Government and Policy:** a. Do you feel that the South African government has effectively communicated and implemented policies related to the energy transition and its impact on the coal mining sector?

b. In your opinion, what social challenges might arise as a result of changes in the coal mining sector due to the energy transition?

7. **Transition to Renewable Energy:** a. How supportive are you of South Africa's shift towards renewable energy sources?
   - Very Supportive
   - Somewhat supportive

b. Do you believe the transition to renewable energy can be achieved without adversely affecting the economy of coal-dependent regions

- Yes
- No
- Maybe

8. **Personal Experiences:** a. Have you or anyone you know been personally affected by changes in the South African coal mining sector related to the energy transition?
   - Yes
   - No
   - Maybe

b. If yes, could you briefly share your experience or the experience of someone you know?

9. **Future Perspectives:** a. In your opinion, what measures can be taken to mitigate the negative effects of the energy transition on the South African coal mining sector?

b. How do you envision the future of the coal mining sector in South Africa in the context of the ongoing energy transition?

10. Additional Comments: Please provide any additional thoughts or comments you may have regarding the energy transition and its impact on the South African coal mining sector.

Appendix C: Interview questions for senior managers

1. How would you describe the current state of the coal industry in South Africa and its future outlook, given the transition towards cleaner energy sources?
2. How is your company responding to the energy transition, and what steps have your company taken to adapt to the changing market conditions?
3. In your opinion, what are the main challenges facing the coal industry in South Africa as a result of the energy transition, and how is your company planning to address them?
4. How has the transition to renewable energy sources affected the demand for coal, and what impact has this had on your company's operations and profitability?
5. How is your company managing the social and environmental impacts of your operations, including issues such as air pollution and climate change?
6. What role do you see for coal in the energy mix of South Africa in the future, and how do you think the government's energy policies will affect the industry going forward?
7. How is your company working with other stakeholders, such as labour unions, local communities, and government agencies, to navigate the energy transition and ensure the sustainability of your operations?
8. What opportunities do you see for the coal industry in South Africa in the context of the energy transition, such as developing new technologies or markets?
9. How does your company plan to invest in the development of clean coal technologies to mitigate the environmental impacts of coal mining and power generation?
10. How does your company plan to balance the need for continued economic growth and job creation in the coal industry with the imperative to reduce greenhouse gas emissions and mitigate climate change?