Electricity supply shocks and industrial performance of the mining sector in South Africa: An econometric approach

CF Manamela

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Electricity supply shocks and industrial performance of the mining sector in South Africa: An econometric approach

by

CHUENE MANAMELA
(230711251)

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Supervisor: Dr Maria Eggink

Co-Supervisor: Prof Andrew Maredza

ABSTRACT

Electricity is essential for economic growth, particularly in energy-intensive sectors like mining. In South Africa, electricity loadshedding has significantly disrupted economic activities and reduced productivity. This study investigates the effects of supply shocks on the mining industry, which depends on a consistent electrical supply for its operations. It identifies the factors contributing to decrease in electricity supply, such as aging infrastructure, constrained energy generation capacity, and inadequate investment in new power plants and alternative energy sources. The economic impact is profound, particularly in energy-intensive sectors like mining. The research employs a quantitative approach (ARDL approach) to estimate the impact of supply shocks on industrial production, with a specific focus on the mining sector. This study uses annual data from 1990 to 2022 to analyse the relationship between electricity distribution, GDP, mining production, Gross Fixed Capital Formation in mining and quarrying, and Total Factor Productivity in South Africa. Data sources include StatsSA, SARB, and OECD. The results indicate a significant long-term relationship between mining production and key economic variables, including electricity availability, GDP, and total factor productivity. The findings emphasise the importance of a stable electricity supply, investment in infrastructure, and technological innovations for maintaining mining productivity. The study reveals that a 1% increase in electricity available for distribution is associated with a 13.32% increase in mining production. Gross fixed capital formation in mining positively impacts mining production, with a 1% increase resulting in a 2.32% rise in output. Total factor productivity shows a negative relationship with mining production, suggesting that technological advancements may reduce the need for high levels of raw material extraction. The Error Correction Model indicates a rapid adjustment process to equilibrium, with an adjustment speed of 112.9%, highlighting the mining sector's resilience to disruptions. Addressing energy supply shortage requires substantial investment in energy infrastructure and diversification of energy sources to ensure a reliable electricity supply, which is crucial for the mining sector's sustainability and growth.

Keywords: Electricity, Economic Growth, Energy-Intensive Sectors, Mining, South Africa, Loadshedding

DECLARATION

I *Chuene Manamela (230711251)* declare that the work titled "*Electricity Supply Shocks and Industrial Performance of the Mining Sector in South Africa: An econometric approach*" is entirely my own. All sources and references used or quoted have been properly cited and acknowledged. Additionally, this work has not been submitted for any other degree or qualification at any other institution, including the University of Mpumalanga.

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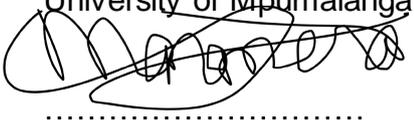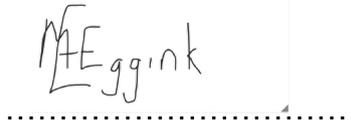
Chuene Manamela   **Dr Maria Eggink**   **Prof Andrew Maredza**

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ABBREVIATIONS

ADF: Augmented-Dickey Fuller test

AIC**: Akaike Information Criterion

ANC: African National Congress

ARCH: Autoregressive Conditional Heteroskedasticity

ARDL: Autoregressive Distributed Lag

CO$_2$: Carbon dioxide

CSIR: Council for Scientific and Industrial Research

CUSUM: Cumulative Sum

CUSUMSQ: Cumulative Sum of Squares

CV: Critical Values

EAF: Energy Availability Factor

ECM: Error Correction Model

ECT: Error Correction Term

ED: Electricity available for distribution

EKC: Environmental Kuznets Curve

FDI: Foreign Direct Investment

GDP: Gross Domestic Product

GFCF: Gross Fixed Capital Formation

GFCFM: Gross Fixed Capital Formation: Mining and Quarrying

JETP: Just Energy Transition Partnership

K: Capital stock

LM: Lagrange Multiplier

MM: Mismatch between demand and supply

MP: Mining Production

NDP: National Development Plan

NER: National Energy Regulator

OECD: Organisation for Economic Cooperation and Development

PAYE: Pay As You Earn

PGM: Platinum Group Metals

PP: Philipps-Perron

PWC: PriceWaterhouseCoopers

R&D: Research and Development

REIPPPP: Renewable Energy Independent Power Producer Procurement Programme

SARB: South African Reserve Bank

SARS: South African Revenue Services

SME: Small and Medium-sized Enterprises

SONA: State of the Nation Address

StatsSA: Statistics South Africa

TFP: Total Factor Productivity

TO: Trade Openness

VECM: Vector Error Correction Model

VIF: Variance Inflation Factor

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 Introduction

Electricity is essential for fuelling the economic growth of a country as it is crucial for energy-intensive sectors such as mining, manufacturing, and agriculture. A sufficient electricity supply enables entities to effectively transform input in the production process into output. Electricity supply shortage which results in loadshedding is becoming more common on a worldwide scale, especially in the underdeveloped economies. Using a simple demand and supply theory, loadshedding occurs when the amount of electricity supplied by the power utilities is insufficient to cover growth in the electricity demand, resulting in market dis-equilibrium or inefficiency (electricity loadshedding). South Africa has faced electricity shortages since before the 2008/09 financial crisis (Inglesi and Pouris, 2010).

Loadshedding began in 2007 which was as a result of shortage in electricity supply, and in 2023, it was officially declared a national disaster during the State of the Nation Address (SONA, 2023). Odhiambo (2009) asserts that the rising electricity demand compelled Eskom, the largest electricity provider in South Africa, to take essential precautions to prevent a nationwide blackout. Electricity loadshedding, as highlighted in the State of the Nation Address (SONA, 2023), is driven by aging infrastructure, limited energy generation capacity, and insufficient investment in new power plants and alternative energy sources. These issues have led to frequent power cuts, with stages ranging from one to six, where stage six can result in up to eight hours of electricity outages per day. This significantly hampers productivity, especially for companies and individuals without alternative energy solutions, reducing work hours from eight to four during severe stages. The economic implications are profound, causing financial losses and operational disruptions.

According to Pierce and Roux (2022), after the first implementation of loadshedding in 2007/08, it was suspended and it was reintroduced six years later in November 2014, marking the first instance of stage 3 loadshedding. It then stopped for two years in 2016 and 2017. In 2015 there were about 852 hours of loadshedding, while 2018 had

127 hours of loadshedding. In 2020 South Africa experienced 859 hours of loadshedding, and it rose sharply in 2021 to 1 169 hours (48 days) of loadshedding and 3 773 hours in 2022. Since the beginning of 2023, South Africa has been constantly experiencing stage 6 (where entities and households can go without electricity for 8-9 hours a day) which is likely to cause more damage to economic growth, especially affecting the energy intensive sectors.

Lenoke (2017) and Goldberg (2015), have investigated the impact of loadshedding on the economic growth of South Africa and specific sectors, there is limited literature on the implications for the mining sector. Despite the mining sector's declining contribution to economic growth, it remains important for employment, government tax revenue, export income, and the country's GDP. The mining sector's contribution to South Africa's economic growth fell from 21% in the 1980s to 8% in 2022, attributed to several factors, including frequent power outages, logistical challenges, fluctuating global demand and prices for minerals, rising crime and corruption, stricter environmental regulations, and the diversification of the economy towards finance and services (StatsSA, 2017). These issues have significantly impacted the mining industry's profitability and sustainability. In 2023, the mining sector constituted over 25% of South Africa's overall export income, highlighting the importance of commodities like platinum, gold, and coal as primary exports generating income from global markets (Minerals Council South Africa, 2023).

Electricity shortages have a pronounced impact on energy-intensive sectors, as highlighted by the South African Reserve Bank (SARB, 2022). The SARB employed a regression model to examine the implications of loadshedding on economic growth, revealing that an increase in the intensity of loadshedding results in a 0.09% decline in economic growth. This finding underscores the critical importance of a stable and reliable energy supply for sustaining economic stability and growth. The effects of loadshedding extend beyond immediate productivity losses, affecting long-term economic prospects and investor confidence. Addressing this issue requires a multifaceted approach, including investment in modernising infrastructure, expanding energy generation capacity, and diversifying energy sources.

The topic of loadshedding has gained significant attention in South African literature. Lenoke (2017) explored the impact of power cuts, electricity consumption, and

electricity prices on the overall economy of South Africa. Goldberg (2015) focused on the effects of loadshedding on the retail sector, highlighting the challenges businesses face during power outages. Inglesi-Lotz and Ajmi (2021) investigated the impact of rising electricity prices and intermittent supply on Foreign Direct Investment (FDI) in South Africa, revealing how energy instability can deter international investors. Inglesi-Lotz and Mabungu (2022) investigated the impact of imbalanced electricity supply and demand on economic growth, highlighting the necessity of aligning supply with demand. Collectively, these studies emphasize the vital role of electricity in South Africa's economic development. Notably, Inglesi-Lotz and Mabungu (2022) discovered that when electricity supply surpasses demand, it enhances economic growth in the long term. Their findings underscore the importance of a stable and adequate electricity supply for promoting economic stability and growth in South Africa.

In this study, the intention is to contribute to the existing literature in South Africa by focusing on the implications of supply shocks on the mining sector. The mining sector is vital in South Africa, significantly contributing to employment, tax revenue, and economic output. Mining operations rely on electricity for machinery, ventilation systems, pumping infrastructure, and underground conveyors. A shortage in electricity supply can substantially reduce productivity in the mining sector. This study aims to provide a deeper understanding of how loadshedding affects one of South Africa's key economic drivers. A quantitative approach is used to estimate the impact of supply shocks on industrial production, with a particular focus on the mining sector.

1.2 Problem statement

Since late 2007, South Africa has faced ongoing electricity supply challenges due to Eskom's insufficient capacity in power generation and distribution. In response, Eskom implemented loadshedding as a corrective measure to mitigate the risk of a complete grid collapse. This has led to regular power cuts across the country, severely affecting economic activity. The mining sector, being one of the most energy-intensive industries and crucial for employment, government tax revenue and export income is particularly affected. Throughout late 2007 and the first quarter of 2008, blackouts became widespread, significantly damaging the South African economy (Inglesi and

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Pouris, 2010). The persistent electricity shortages have hampered production, discouraged investment, and eroded confidence in economic stability. If these conditions continue, the country could face prolonged slow growth and a further decline in investor sentiment.

According to Mining Indaba (2023), most mines can manage intermittent power disruptions at stages one to four however struggle significantly at stages five and six. Mining Indaba (2023) notes that continued implementation of higher stage loadshedding may compel firms to scale back operations or reduce their workforce. Investor confidence in the mining sector has declined notably since 2018, according to the Minerals Council (2022). Even though Pay As You Earn (PAYE) tax contributions from the mining industry have grown from R15 billion in 2015 to R34 billion in 2023, corporate income tax collections have shown volatility. Collections fell from R13.8 billion in 2015 to R7.9 billion in 2016, rose sharply to R89 billion in 2021, then dropped to R44.3 billion by 2023 (SARS, 2023). These fluctuations reflect the instability in mining profits caused by unreliable electricity supply.

In 2022, Eskom imposed a 15% electricity reduction on mining companies, which led to a 3.7% decline in mining production (News24, 2023). If the electricity supply shortage continues, the mining sector may be forced to further downsize, increase operating costs, and reduce employment. These developments would directly impact their profit margins, job creation and limit their government tax contributions.

Although loadshedding was introduced as a temporary solution to stabilise the power grid, it has not addressed the underlying structural problems of limited capacity, aging infrastructure, and lack of investment in energy diversification. As a result, loadshedding continues to disrupt vital industries without offering a long-term resolution.

This study seeks to investigate the specific impacts of electricity shortage on South Africa's mining sector, focusing on both the short term and long term consequences for production, employment, and revenue. While the sector's overall contribution to economic growth has declined, it remains a cornerstone of the national economy. Despite its importance, limited research exists on the direct implications of electricity shortages for mining. This study aims to fill that gap and provide insights that could support more effective policy and industry responses.

1.3 Research questions

The main research question is: how does electricity supply shocks affect industrial performance of the mining sector in South Africa?

The sub-questions are:

- What do empirical studies reveal about the relationship between supply shocks and industry performance?

- How has the frequency and severity of energy supply shortage evolved in South Africa over the years?

- What are the long-term and short-term effects of energy supply shocks on mining production in South Africa?

- What measures can be proposed to alleviate the negative impacts of electricity supply shortage on the mining industry?

1.4 Objectives of the study

The main aim of the study is to establish the impact supply shocks on the mining sector of South Africa. The specific objectives are as follows:

Objective 1: To determine the empirical findings as described in literature on the impact of loadshedding on mining industry.

Objective 2: To investigate the progression of electricity supply shortage in South Africa, focusing on its frequency, severity, and underlying causes over time.

Objective 3: To determine the effect of electricity supply shortage (independent variable) on the production levels of the South African mining sector (dependent variable) in both the short term and long term.

Objective 4: To provide recommendations for mitigating the adverse effects of electricity supply shortage on the mining industry based on the findings of this study.

1.5 Hypothesis of the study

This study tests the following hypothesis.

- H_0: Electricity supply shocks do not have a significant impact on the mining sector in South Africa

- H_1: Electricity supply shocks exhibit a significant impact on the mining sector in South Africa

1.6 Significance of the study

Empirical evidence indicates a significant correlation between electricity generation and economic growth in South Africa (Lenoke, 2017; Inglesi-Lotz and Mabungu, 2022; Inglesi-Lotz and Ajmi, 2021). Walsh, Theron, and Rees (2021) estimated the cost of loadshedding across various economic sectors, excluding the mining industry. This study explored the impact of electricity shortages on the South African economy and the mining sector, enhancing the existing literature and providing a resource for future research. Additionally, it aims to assist policymakers with estimates and forecasts related to mining production and economic growth.

1.7 Delimitations of the study

- This study exclusively examines the implications of shortage of electricity supply on mining production in South Africa.

- It considers only the electricity available and distributed by Eskom within South Africa.

- The dataset utilised in this study spans from 1990 to 2022 due to the availability of the data.

- The study focuses solely on electricity provided by Eskom in South Africa, excluding any considerations of electricity supply in neighbouring countries.

1.8 Structure of the study

The study is structured into six chapters. Chapter 1 provides the background, aims, and objectives of the study. Chapter 2 reviews the history of electricity supply in South Africa, detailing the initial implementation of loadshedding and its implications on the mining sector in terms of employment, revenue collection, and exports. Chapter 3 examines both empirical and theoretical perspectives on the impact of electricity on the mining sector. Chapter 4 outlines the methodologies used to achieve the study's objectives, including detailed explanations of the tests employed. Chapter 5 presents the results derived from the methodologies discussed in Chapter 4, which are then used to draw conclusions and make recommendations. Finally, Chapter 6 summarizes the key findings, conclusions, and recommendations of the study.

CHAPTER TWO

AN OVERVIEW OF THE ENERGY AND MINING SECTOR IN SOUTH AFRICA

2.1 Introduction

The topic of electricity supply shortage or electricity loadshedding has gained the interest of many policy makers' and academics' interest. Loadshedding negatively impacts on production in different industries however, the severity of its impact depends on how much the sector relies on electricity to produce goods and services. This section describes the energy sector in South Africa, detailing the history and causes of loadshedding and exploring its implications for the mining industry.

2.2. The overview of the energy sector in South Africa

According to the National Planning Commission (2012) in their 2012 National Development Plan (NDP) document, all South Africans, or at least 95% of South Africans, should have access to the electricity and have diverse energy sources such as gas, wind, and solar, which would supply almost 20% of energy by 2030 (National Planning Commission, 2012). The NDP objective seems to be unrealistic, South Africa is experiencing an energy supply shortage and a growing energy demand. Africa contributes approximately 3% of the world's electricity generated, and about one third of that is generated in South Africa, therefore, making South Africa the top leading energy supplier in Africa (Akinbami, Oke and Bodunrin, 2021).

The three phases of electricity are depicted in the figure 2.1 below:

Figure 2.1: Electricity production procedure
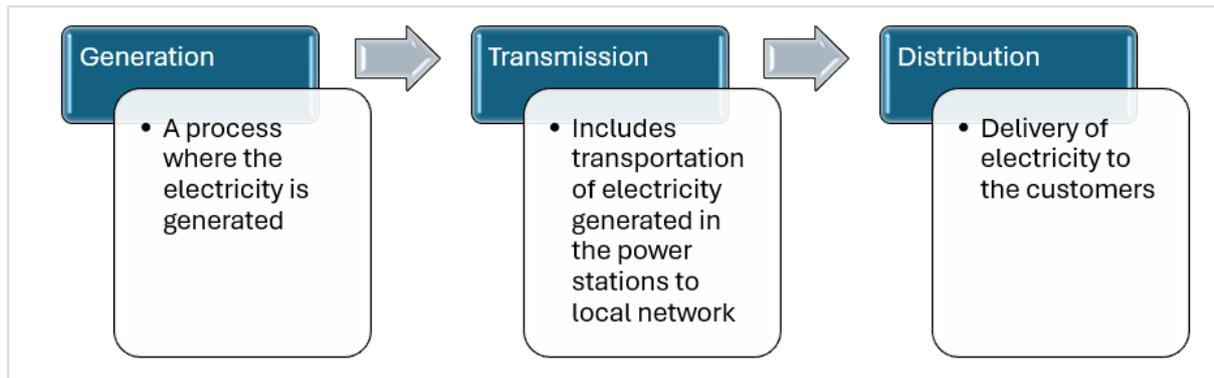
Source: Author's compilation using Vizzlo software

The delivery of energy from generation to end-users comprises three primary stages: generating, transmission, and distribution. During the generation phase, electricity is produced through diverse methods, including thermal power plants that combust coal, natural gas, or oil; hydroelectric power plants that exploit the energy of flowing water; nuclear power plants that utilise nuclear reactions; and renewable sources such as solar panels and wind turbines. After generation, electricity must be conveyed to various destinations, which is the function of the transmission phase. This entails high-voltage transmission lines that transport electricity across extensive distances from power plants to substations, where the voltage is reduced to a lower level appropriate for distribution. Ultimately, in the distribution phase, power is transmitted to customers via local distribution networks. These networks transmit energy from substations to residences, enterprises, and other consumers, with transformers subsequently lowering the voltage to a safe level for utilisation. This mechanism guarantees the effective and safe delivery of electricity generated at power plants to consumers (Eskom, 2023).

Electricity generation and transmission are largely the function of Eskom in South Africa whereas in some area's municipalities have their generation capacity, which in most cases is not sufficient to cover the demand. According to the Eskom Report (Eskom, 2022), Eskom can only directly distribute to six million households and entities in South Africa, and for the rest of the population, electricity is distributed to municipalities, which then redistribute it to the households and consumers (Eskom, 2022).

Eskom also provides electricity to the neighbouring countries such as Botswana, Lesotho, Mozambique, eSwatini, and Zimbabwe due to bilateral and power purchase agreements (Eskom, 2019). During supply difficulties, Eskom halts all sales to Namibia and Botswana and reduces deliveries to other neighbouring countries by 10%. To address electricity shortages in South Africa, Eskom imports electricity from Mozambique, Lesotho, Zambia, and Zimbabwe to meet the increasing demand (News24, 2022).

Eskom operates 30 power stations in South Africa which collectively can generate, for example, 54 669MW in 2022 (depicted in figure 2.2 below). The coal-fired stations are the main contributors to electricity generation, with a capacity of 39 800 MW. In 2022, coal reserves fell below the 80% threshold for the first time. This means that the available coal reserves were less than 80% of the total storage capacity. Such a decline is significant, as it suggests a reduction in coal supply, potentially affecting energy production, pricing, and overall energy security (Eskom, 2022).

Additionally, Eskom's energy generation capacity includes 2 724 MW from pumped storage, 2 409 MW from gas-fired stations, 1 860 MW from nuclear power, 100 MW from renewable sources (such as the Sere wind farm), and 600 MW from hydroelectric stations (Eskom, 2023).

Figure 2.2: Electricity Sources in South Africa
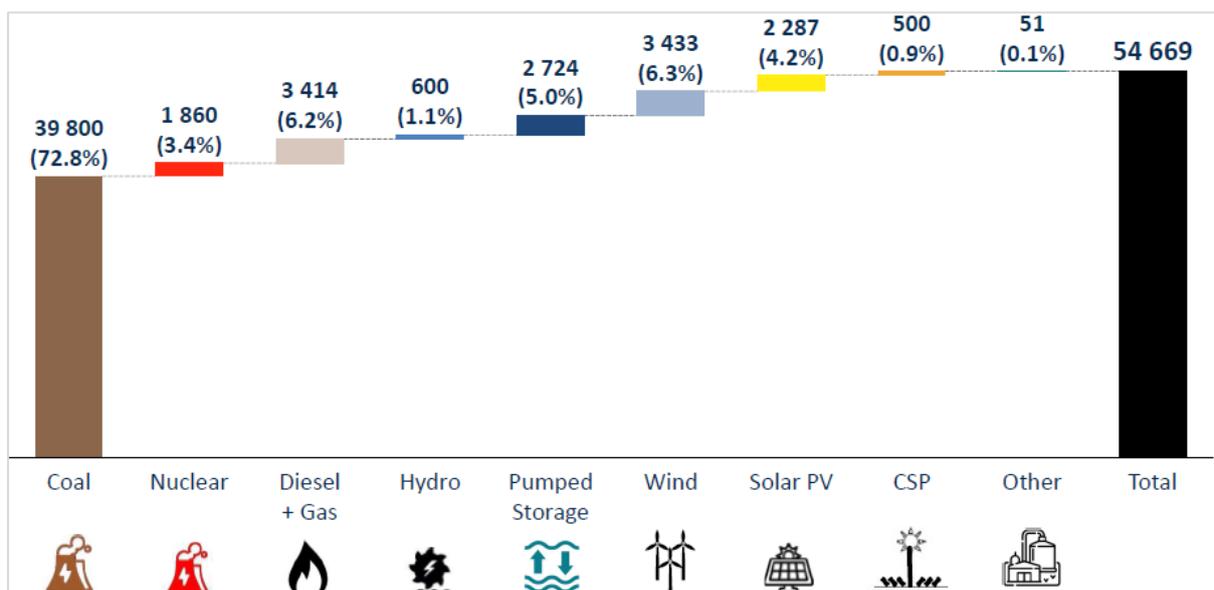
Adopted from: Pierce and Le Roux, 2022

The top three biggest power stations in South Africa are Medupi power station in Limpopo, Kusile power station in Mpumalanga, as well as Kendal power station in Mpumalanga.

2.3. Measures implemented by the government to alleviate energy supply shortage, progress and challenges in transitioning to green energy

South Africa has achieved considerable progress in its shift to green energy, chiefly via the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). This effort has been essential in drawing private investment and promoting the advancement of renewable energy projects nationwide. Currently, South Africa possesses roughly 5 GW of installed renewable energy capacity, with various wind and solar projects either operational or under development. The country's advantageous solar and wind conditions have enabled the development of these projects, which enhance the national grid, generate employment opportunities, and invigorate local economies (Department of Mineral Resources and Energy, 2023).

The Just Energy Transition Partnership (JETP) is an international programme aimed at facilitating South Africa's transition from a coal-dependent energy framework to cleaner, renewable sources like wind, solar, and hydrogen while promoting social fairness. The collaboration, involving global participants such as the United States, the European Union, and the United Kingdom, has committed $8.5 billion in financial assistance. The JETP aims to decarbonise the energy industry, generate employment opportunities, retrain workers in coal-reliant communities, and upgrade energy infrastructure (Presidential Climate Finance Task Team 2022). However, challenges in implementing of JETP, include slow financial disbursement and concerns over the pace of project execution, which delay progress in addressing South Africa's immediate energy crisis. Policy uncertainty and governance challenges impede efficient implementation, while insufficient cooperation among diverse stakeholders hinders the attainment of JETP's social and environmental objectives (News24,2024).

The Integrated Resource Plan (IRP) serves as South Africa's power planning framework, outlining strategies for a sustainable energy mix to ensure a reliable electricity supply. The plan sets objectives for transitioning to renewable energy sources, including wind and solar, while reducing dependence on coal. The IRP aims

to balance energy security, cost-effectiveness, and environmental sustainability through diversification, enhancing renewable capacity, and modernising the grid (Montmasson-Clair and Ryan, 2014). However, the IRP faces obstacles in its execution. Regulatory issues, financial constraints, and slow investment in renewable technology hinder progress. Reliance on outdated coal infrastructure leads to frequent power outages, and the grid is inadequate for integrating renewable energy. Political instability and policy inconsistency further complicate implementation. Addressing these challenges requires increased investments, stable legislative frameworks, and upgraded infrastructure to meet South Africa's growing energy needs and environmental goals (Meridian Economics, 2024).

Notwithstanding these achievements, the shift to green energy in South Africa faces significant hurdles, such as infrastructure, finance, and investment challenges. The energy sector is predominantly reliant on coal, which constitutes approximately 80% of electricity production. The reliance on coal has significant environmental and health implications, including increased air pollution and greenhouse gas emissions. Transitioning to renewable energy requires substantial investment in infrastructure, particularly in upgrading the national grid to accommodate intermittent renewable sources and ensure a dependable electrical supply (International Energy Agency, 2023).

2.4. Causes of shortage in electricity supply in South Africa

Since the 1970s, both developing and developed economies have encountered shortages in electricity supply. Examples of countries with issues of electricity supply are New York City and Western Europe. New York City in North America has experienced several major power failures, notably in July 1977. Similarly, Western Europe faced significant blackouts during the winter of 1978-79, primarily due to weather-related events such as wildfires and storms (Muganasinghe, 1979). More recently, these regions have continued to experience blackouts. For instance, in 2020, North America experienced blackouts due to severe storms and winter weather, while Western Europe faced blackouts in the same year due to grid failures. According to Eskom (2023a), loadshedding is defined as "the controlled/planned power disruption

by Eskom and municipal control rooms in an emergency to lower demand". Loadshedding in South Africa started in 2007; however, there were clear signs that the country might experience electricity shortages as early as 2003.In the 2004 State of the Nation Address (SONA), President Thabo Mbeki announced a policy ensuring power access for all South Africans by 2012 (SONA, 2004). The main plan was to connect people to the electricity grid, but there were also plans to invest in alternative avenues for generating electricity.

In South Africa, the ongoing decrease in electricity supply, resulting in loadshedding, is caused by several factors. These include the increasing demand for electricity, aging infrastructure, insufficient investment in renewable energy sources and operational inefficiencies, and corruption. Each of these factors contributes significantly to the country's energy crisis, making it difficult to maintain a reliable and sustainable power supply.

Through the electrification programme, approximately 7.8 million households were connected to the grid by 2004, a significant increase from the 3 million households connected in the 1990s. While most formal urban areas gained access to electricity, challenges arose in rural areas due to the high costs and the need for extended transmission networks and transformers. By 2006, the rate of electrification had declined sharply, with only 150,000 households being connected. The programme also faced issues as Eskom funded the electrification through cross-subsidies (World Bank, 2022).

In 2007, Eskom made the critical decision to introduce loadshedding due to a surge in electricity demand and a significant drop in reserve capacity, which had dwindled to between 8% and 10%, far below the desired 15%. This measure was essential to prevent widespread blackouts that could result from the cascading failure of generating units and power lines, potentially leading to a complete loss of power supply across the country. To mitigate the immediate crisis, Eskom undertook the resurfacing of three power stations being: Camden, Grootvlei, and Komati. This effort added approximately 1,450 MW to the national grid. However, this addition was insufficient to meet the rapidly escalating demand for electricity. Recognising the need for a more substantial and long-term solution, Eskom initiated the construction of the Medupi and Kusile power stations in 2008. Each of these stations were designed to

contribute about 4,800 MW to the system, significantly boosting the country's power generation capacity. Despite these efforts, the construction of Medupi and Kusile faced numerous setbacks. Policy changes, corruption, and funding shortages caused significant delays, exacerbating the challenges Eskom was already facing. These delays not only hindered the timely completion of the power stations but also strained the existing infrastructure, making it difficult to keep up with the increasing electricity demand (Eskom, 2012).

Montmasson-Clair and Ryan (2014) indicate that electricity price increases adversely impacted the competitiveness of specific mining and smelting value chains in South Africa. Loadshedding in 2008 led to the closure of most mines for a week, disrupting production, as energy stability is crucial for the mining sector. Loadshedding cost the country an estimated $2.2 billion in GDP in 2008, which forced the permanent closure of several mines (Calldo and Myburgh, 2008). About 16 years later, the problem has peaked with constant rolling blackouts and has reached a record high in January 2023 when the country started experiencing stage 6 loadshedding (Erero, 2023).

Figure 2.3: History of electricity loadshedding in South Africa

Load shed, upper-limit [GWh]

Year	of outages (hours)	shed (GWh)	(GWh)
2007	-	176	Not available
2008	-	476	Not available
....	....	....	....
2014	121	203	Not available
2015	852	1 325	Not available
....	....	....	....
2018	127	192	392
2019	530	1 352	1 362
2020	859	1 798	1 426
2021	1 169	2 521	1 936
2022	3 773	11 529	8 301

Legend: Unknown | Stage 6 | Stage 5 | Stage 4 | Stage 3 | Stage 2 | Stage 1

Notes: Loadshedding assumed to have taken place for the full hours in which it was implemented. Practically, load shedding (and the Stage) may occassionally change/ end during a particular hour; Total GWh calculated assuming Stage 1 = 1 000 MW, Stage 2 = 2 000 MW, Stage 3 = 3 000 MW, Stage 4 = 4 000 MW, Stage 5 = 5 000 MW, Stage 6 = 6 000 MW

Adopted: Pierce and Le Roux, 2022

Figure 2.3 shows loadshedding trends in South Africa since its inception. Loadshedding started to increase significantly in 2019/20. In 2022, the country experienced about 3 773 hours (157 days) of electricity loss, which was significantly higher than in 2020 and 2021 collectively. In 2023, the country has been experiencing

loadshedding almost every day. By 16 April 2023 the country had already experienced 2 434 hours of loadshedding (Loewald, 2023).

The Energy Availability Factor (EAF) measures the performance of the power plant. It indicates the availability of electricity and how reliable the power plants are. Around 2000, the EAF was approximately 80% compared to 67% a decade later in 2019. This has resulted in a constant increase in the shortage of electricity supply (Davis, 2021). The EAF further declined to 58% in 2022, down from 62% in 2021 and 65% in 2020, which is well below the 75.5% Eskom target (Erero, 2023). Around the first week of January 2023, Eskom's EAF was around 49.5% (Eskom, 2023).

Figure 2.4: Loadshedding stages in South Africa

Source: Author's compilation using Vizzlo software

Loadshedding in South Africa is categorised into stages ranging from one to eight, as illustrated in Figure 2.4 above. The higher the stage, the more frequent and severe the power outages. For instance, during stage three, individuals experience power cuts 12 times over four days, with each outage lasting two hours (Davis, 2021). In recent years, South Africa has predominantly faced stages one to four, which, while disruptive, were somewhat manageable. However, the situation has significantly worsened since 2022. The country has increasingly encountered stage six

loadshedding, where households and businesses can be without electricity four to five times a day, each outage lasting two hours. This escalation has had a profound impact on daily life and the economy.

Since the beginning of 2023, stage six loadshedding has become a regular occurrence, severely affecting industrial performance and productivity. The frequent power cuts disrupt manufacturing processes, reduce output, and increase operational costs. Small businesses, in particular, struggle to cope with the unpredictability and duration of the outages, often leading to financial losses and, in some cases, closures. In response to these challenges, many households and businesses have invested in alternative power sources such as generators, solar panels, and battery storage systems. While these solutions provide some relief, they are often expensive.

South Africa faces several challenges in its transition to a more sustainable energy future. Despite progress through initiatives like the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), which has attracted private investment and expanded renewable energy capacity, issues such as aging infrastructure, financial constraints, and slow investment in new technologies persist (Department of Mineral Resources and Energy, 2023). The Just Energy Transition Partnership (JETP), aimed at decarbonising the energy sector and promoting social fairness, encounters delay in financial disbursement and concerns over the pace of project execution. Policy uncertainty, governance issues, and insufficient cooperation among stakeholders further hinder the achievement of its social and environmental objectives (Presidential Climate Finance Task Team, 2022; News24, 2024). Additionally, the Integrated Resource Plan (IRP), which guides South Africa's energy strategy, faces obstacles including regulatory challenges, financial limitations, and an outdated grid, all of which impede the integration of renewable energy and contribute to frequent power outages (Montmasson-Clair and Ryan, 2014; Meridian Economics, 2024).

2.5. Mining production in South Africa

South Africa is among the most resource-abundant economies globally, and the mining sector has significantly contributed to attracting foreign direct investment (Antin, 2013). Mining is not only a significant sector in South Africa but also in the neighbouring countries and is known to be one of the most energy-consuming sectors for production. According to Greenpeace (2012), the mining industry used 14.3% of the energy generated by Eskom in 2011 (Boyse, Causevic, Duwe and Orthofer, 2014).

With loadshedding, most mining companies are forced to either reduce production or opt for high-cost diesel-powered generators (Alternative Energy in Mining, 2013). With mines located in remote areas, far from the transmission line, diesel generators become their only option, which negatively impacts their profit margins. According to Boyse, Causevic, Duwe and Orthofer (2014), mines operating off grid might reduce their energy costs if they opt for renewable energy.

Mining in South Africa commenced in 1867 with the discovery of the first diamonds in the Orange River. Two years later, diamonds were discovered in lucrative quantities in Kimberly, within the kimberlite diamond matrices (Africa Mining IQ, 2023). By 1880 all mines around Kimberly had collectively produced about 95% of the world's diamonds. Shortly after the discovery of diamonds, gold was discovered and became the major source of export income and GDP contributor. The mining sector emerged as a major contributor to the South African economy in the 1860s (StatsSA, 2017). In 1980, the industry's contribution to economic growth was 21% and had employed about 700 000 people. In 1987, the mining industry saw its highest employment levels, with just over 760 000 individuals employed in the sector (StatsSA, 2017).

The mining sector was the second largest GDP contributor in 1980 (21%). The sector was outperformed by other sectors when it started to decline significantly in 2016, and the mining industry contributed only 8% (StatsSA, 2017). Despite a decline in its contribution to economic growth over the years due to logistical challenges, electricity supply disruptions, high operating costs, and regulatory uncertainty, the mining sector remains a key player in the economy. It significantly contributes to employment, tax revenue, export earnings, and attracts foreign direct investment. In 2020, the mining

industry provided approximately 1.5 million direct and indirect jobs (Department of Mineral Resources and Energy, 2022).

Figure 2.5: Mining production in South Africa
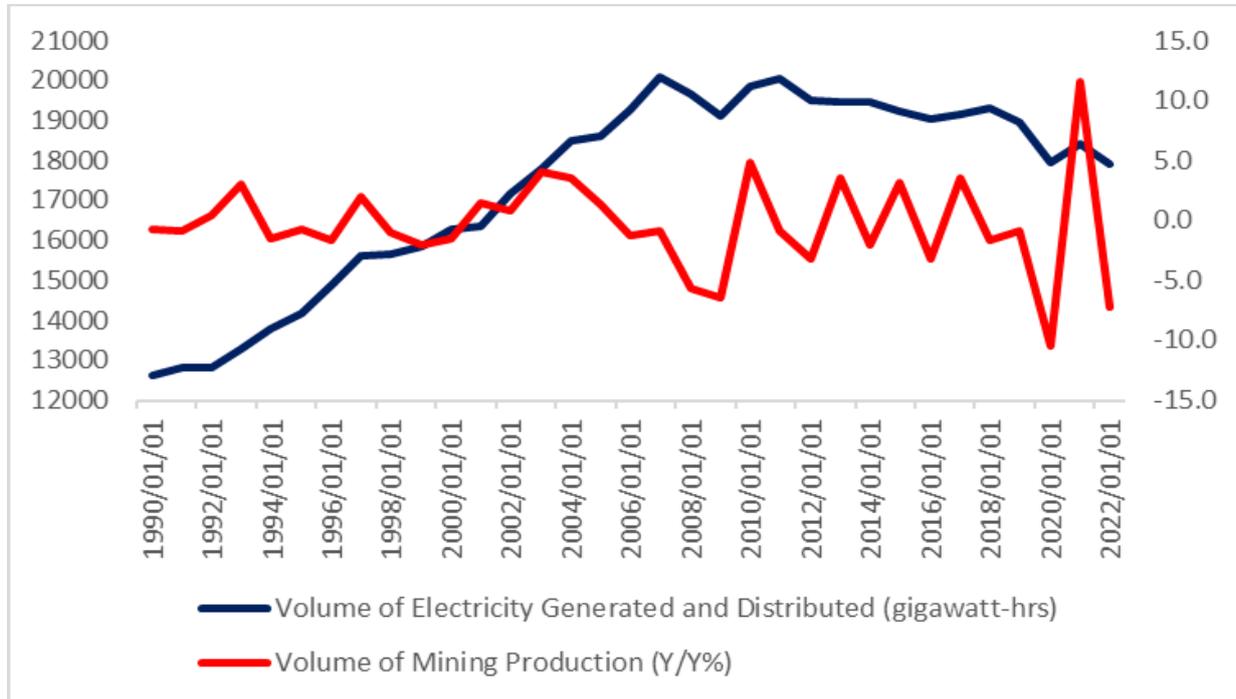
Figure 2.6 illustrates the relationship between mining production and electricity generation and distribution in South Africa. The data suggest a positive correlation, with both metrics generally moving in the same direction. From 1990, electricity generation and distribution exhibited an upward trend, which began to decline around 2007/2008. This downward trend continued from 2012/2013 through 2022, as shown in the graph. The study aims to employ systematic methods to further validate this relationship. Mining production has experienced various trends and shifts since the 1990s. Some of the challenges include declining gold reserves, increased costs, and labour disputes. The sector continues to be pressured by unfavourable pricing conditions in the Platinum Group Metals (PGM) and coal sectors, as well as logistical difficulties in the coal and iron ore industries (World Economic Forum, 2023).

The mining sector in South Africa includes coal, Platinum Group Metals (PGMs), iron ore, gold, manganese ore, chromium, other metallic minerals, nickel, and copper. The country holds the world's largest reserves of manganese and PGMs, along with substantial reserves of gold, diamonds, and coal (StatsSA, 2017). Coal is particularly

vital to South Africa's economy, serving as a major export commodity and a primary energy source. Coal-fired power plants produce most of the country's electricity, making coal essential for both industrial and residential energy needs.

2.5.1 Coal Industry

Coal mining is crucial to South Africa's economy, providing just over 80% of Eskom's electricity supply. However, this percentage fell slightly below 80% for the first time in 2022. Compared to other countries, South Africa is known to be one of the few countries that have the advantage of low-cost production of coal. Coal was first extracted in South Africa from the Highveld coal fields near the Witwatersrand gold mines. The country has 19 coalfields, mainly located in the northeastern regions, including Mpumalanga, Limpopo, and extending to KwaZulu-Natal and the Free State (as illustrated in Table 2.1 below). Key coalfields in production include Ermelo, Highveld, Kangwane, Kliprivier, Nongoma, Soutpansberg, Utrecht, Vereeniging-Sasolburg, Vryheid, Waterberg (Ellisras), and Witbank. The Witbank and Highveld coalfields are the primary sources, accounting for about 75% of South Africa's coal production (DMR, 2016).

Table 2.1: Coal-fired Power Stations in South Africa

	Installed Capacity	Area	
Arnot power station	2 100MW	Middelburg in Mpumalanga	
Camden power station	1 600MW	Ermelo Mpumalanga	
Duvha power station	3 450MW	Witbank in Mpumalanga.	
Grootvlei power station	1 200MW	Balfour in Mpumalanga	
Hendrina power station	2 000MW	Middelburg in Mpumalanga	
Kendal power station	4 116MW	Witbank in Mpumalanga	
Komati power station	1000 MW	Komati, Mpumalanga	
Kriel power station	2850MW	Ogies in Mpumalanga	
Kusile power station	4 800 MW	Nkangala district of Mpumalanga,	
Lethabo power station	3660MW	Sasolburg in the Free State	
Majuba power station	4 110MW	Amersfoort in Mpumalanga	
Matimba power station	3 990MW	Lephalale in the Limpopo Province	
Matla power station	3 600MW	Secunda in Mpumalanga	
Medupi power station	4 800MW	Lephalale, Limpopo	
Tutuka power station	3 654MW	Standerton in Mpumalanga.	

Source: Eskom, 2023

South Africa's coal production is primarily controlled by five major mining companies: Anglo American Thermal Coal, Exxaro Resources, Sasol Mining, BHP Billiton Energy Coal South Africa (Becsa), and Glencore. Together, these companies account for about 80% of the country's annual coal production, with the rest coming from various small and medium-sized producers (Wood Mackenzie, 2015).

Figure 2.6: Coal producers in South Africa
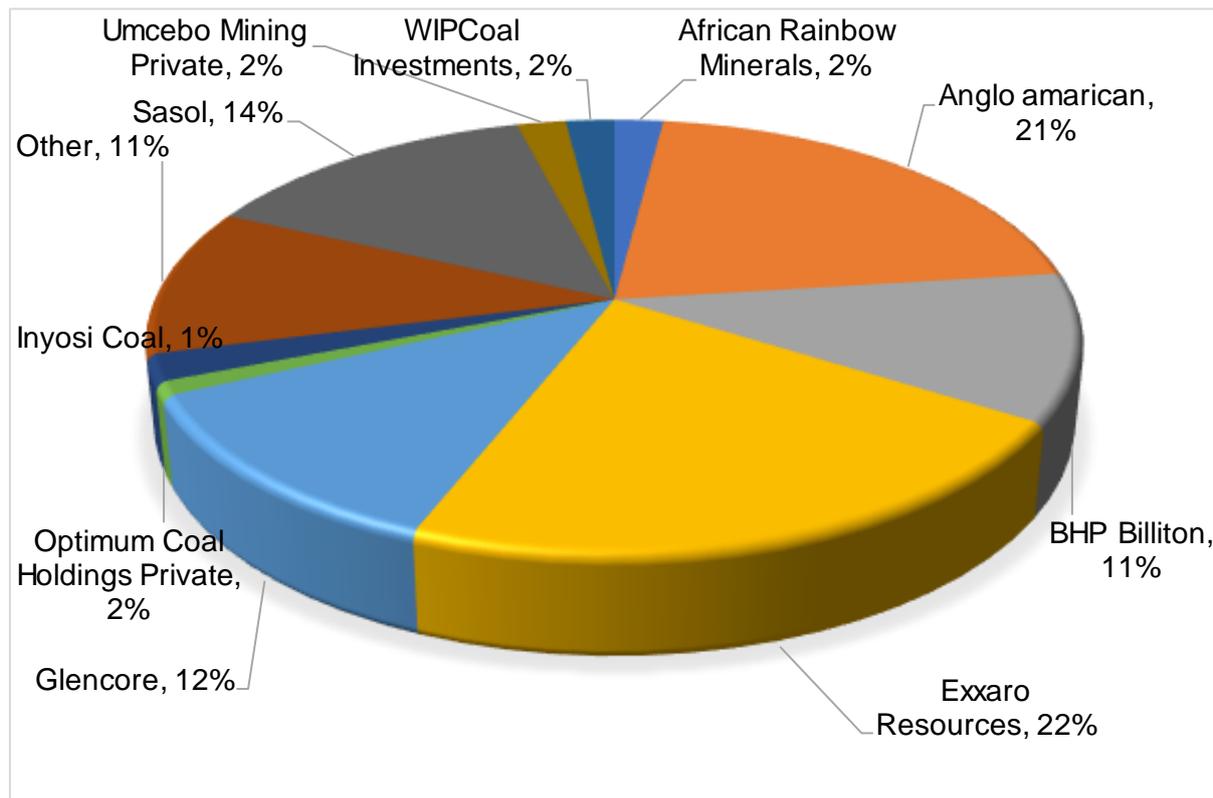
Adopted: Wood Mackenzie, 2015

Between 2006 and 2015, coal exports increased at an average annual rate of 2.6%, rising from 68.7 million tonnes (Mt) to 76.9 Mt. However, exports fell between 2006 and 2009 due to reduced demand from Europe following the global financial crisis. In 2010, exports rebounded by 45% due to increased demand from Asian markets and the recovery of the European economy. Despite this, infrastructure limitations have caused export volumes to stagnate at around 75 Mt since 2012 (Department of Energy, 2016). Recent data reveals changes in South Africa's coal exports. In 2023, South Africa exported over 72 million tonnes of coal, reflecting a 15.1% decline from 2022. The primary destination for these exports was India, which accounted for 41% of the total (Indexbox, 2023). European nations such as the Netherlands, Germany, and Poland have shown a trend of importing larger volumes of coal from South Africa. During the first five months of 2022, European imports from South Africa surpassed 3 million tonnes, reflecting an increase of over 40% compared to the total volume recorded in 2021(Africanews, 2023).

South Africa's coal imports, mainly coking coal, are influenced by the demand from the iron and steel industry, which is tied to the country's economic performance. As a result, coal imports followed the trend of steel production, reaching its peak in 2008 before declining by 17.8% in 2009 as a result of the economic crisis. Imports remained modest until exceeding 1 Megatonne (Mt) in 2013, subsequently declining by 16% in 2015 due to decreased steel production (Department of Energy, 2016).

2.6 Impact of loadshedding on government revenue collection

According to the South African Revenue Services (SARS), the total revenue collection in South Africa is significantly influenced by the country's economic performance, the efficiency of tax administration, and the level of compliance. Economic performance is the primary driver of revenue, meaning that if the economy underperforms, it is likely to negatively impact tax revenue collection. Recent empirical studies from various countries have shown that loadshedding has a detrimental effect on economic growth.

The cost of loadshedding is expected to result in a decline in revenue collection, as it heavily depends on economic performance. The South African Reserve Bank (SARB) used three different forecasting models to estimate the cost of loadshedding in 2022, which ranged from 0.7% to 3.2% of GDP (Loewald, 2023). Other institutions provided varying estimates: Amalgamated Banks of South Africa (Absa) at 1.3%, First National Bank (FNB) at 0.5%, Investec at 0.4%, PricewaterhouseCoopers (PwC) at 4.2%, and Intellidex at 2.2%. Loadshedding reduces business productivity, which in turn negatively impacts profit margins. This decrease in profits directly affects Company Income Tax (CIT) and indirectly affects Domestic VAT. Some companies are forced to shut down due to frequent power cuts. For instance, in 2008, loadshedding caused many mines to shut down for a week. Mining companies are significant employers and contribute substantially to employment taxes (PAYE and PIT) (PWC, 2007).

The mining sector accounted for nearly 30% of provisional corporate tax collections in 2022/23, a significant increase from its average share before 2020/21. However, the sector's contribution declined relative to 2021/22 due to a sustained fall in production and declining terms of trade, which will likely impact PAYE. Elevated commodity prices

have boosted mining tax revenue, but the overall impact of loadshedding remains a concern (Budget Review, 2023).

Loadshedding affects various sectors differently, but the overall impact on the economy is profound. For businesses, frequent power outages mean reduced operational hours, lower productivity, and increased operational costs as they may need to invest in alternative power sources like generators. This not only affects their profit margins but also their ability to expand and hire more employees, which in turn affects personal income tax (PIT) collections.

Moreover, the indirect effects of loadshedding on the economy can be substantial. Reduced business activity leads to lower demand for goods and services, which can result in lower VAT collections. The ripple effect of decreased economic activity can also impact other forms of tax revenue, such as customs duties and excise taxes, as reduced production and consumption lower the volumes of imports and exports.

Loadshedding forces industries like agriculture and mining to rely heavily on diesel generators, significantly increasing their diesel consumption and operational costs. This heightened diesel usage leads to more claims for diesel refunds from revenue authorities, such as the South African Revenue Service (SARS). The increased demand for refunds strains the refund system, posing a risk to the overall revenue collection, and potentially impacting the broader economy through higher costs for goods and services (Erero, 2023).

2.7. Impact of shortage in energy supply on employment in the mining sector

South Africa's high unemployment rates have been exacerbated by several factors, notably the severe power shortages experienced in recent years. PwC highlighted a significant loss of 350 000 jobs in 2022, attributed to the regular implementation of stage 4 loadshedding. By 2023, the situation had deteriorated further, with the country facing stage 6 loadshedding, a trend that continued into March 2024 (PWC, 2024).

The mining sector, a critical component of South Africa's economy, has been particularly hard hit by these power shortages. Employment in the mining sector has

been under pressure for years, with a notable decrease of almost 16% between 1994 and 2011. While employment in the gold mining sub-sector has declined, the PGMs (Platinum Group Metals) mining sub-sector has seen some growth. The mining sector experienced a brief recovery in 2010 and 2011, following the financial crisis of 2009, but was soon impacted by the Marikana tragedy and subdued global growth. In 2022, the mining sector saw a further decline in employment, losing 24 000 jobs and bringing the total down to 413 000 from 436 000 (Quarterly Bulletin, 2023).

The ongoing loadshedding has made it increasingly difficult for mining companies to operate efficiently, leading to further job losses. Without reliable electricity, these energy-intensive operations struggle to maintain productivity, forcing some companies to shut down or reduce their workforce. This has contributed to the overall high unemployment rate in South Africa, which stood at a staggering 32.9% in 2023 (StatsSA, 2023).

The ongoing power shortages have significantly affected employment in South Africa, especially within the mining sector, which faces numerous challenges that hinder its development and growth. The unpredictable environment that investors encounter and the delays in project development are primarily caused by policy and regulatory uncertainty. Corruption continues to be a widespread problem, resulting in a lack of trust among investors and the implementation of unjust practices. Operations and employees are at risk due to security concerns, including theft, violence, and illicit mining. Furthermore, the efficient conveyance of minerals is impeded by infrastructure limitations, particularly in ports and railways (Mineral Council, 2024).

2.8. Contribution of mining sector to export income

The mining sector is fundamental to South Africa's economy and significantly influences the country's balance of payments. In 2023, the mining sector accounted for almost 25% of South Africa's overall export revenue, highlighting its significance in foreign exchange generation and the national balance of payments (Minerals Council South Africa, 2023). The exportation of minerals, including gold, platinum, and coal, generates significant foreign currency inflows, essential for funding imports and sustaining economic stability. The influx of foreign exchange stabilises the South

African rand and bolsters the nation's capacity to fulfil its international financial commitments.

In addition to direct export income, the mining sector invigorates other sectors of the economy through its demand for goods and services. This encompasses areas including manufacturing, transportation, and financial services, generating a multiplier effect that amplifies the overall economic influence of mining. The sector's comprehensive supply chain connections result in substantial economic activity and employment, thereby enhancing the balance of payments by boosting domestic production and diminishing import reliance (Integrated Annual Review, 2023). This interdependence underscores the extensive economic advantages of a strong mining industry.

Nonetheless, the mining sector encounters numerous constraints that may affect its contribution to the balance of payments. Infrastructure limitations, including insufficient rail and port facilities, might hinder the effective export of minerals. Moreover, volatile global commodity prices might influence export income, rendering the sector's contribution to the balance of payments inconsistent and even unpredictable. Confronting these problems necessitates significant investment in infrastructure and regulations that enhance the mining industry's resilience and competitiveness internationally (Rejuvenating South Africa's Economy, 2022).

2.9 Investment in the mining industry

Investing in the mining sector is essential for the global energy transition, technological advancements, and economic development. It is responsible for the development of infrastructure, supports the advancement of new technologies such as electric vehicles and renewable energy systems, and provides essential basic materials for a variety of industries. Modern mining investments are also appealing to investors who prioritise environmental and social responsibility due to their emphasis on sustainability and environmental, social, and governance (ESG) standards. Overall, mining investments are essential for the support of sustainable development and the achievement of global climate objectives (Mining Weekly, 2021).

Investment in the mining industry has increased progressively from 1993 until 2007/08; the growth during that period was about 7.4%. A decline in investments in the mining industry was observed between 2003 and 2005 (Mining Tax, 2013). Investment in the mining industry then started to decline from 2014 and again from 2019 to 2021.

Figure 2.7: Gross Fixed Capital Formation: Mining
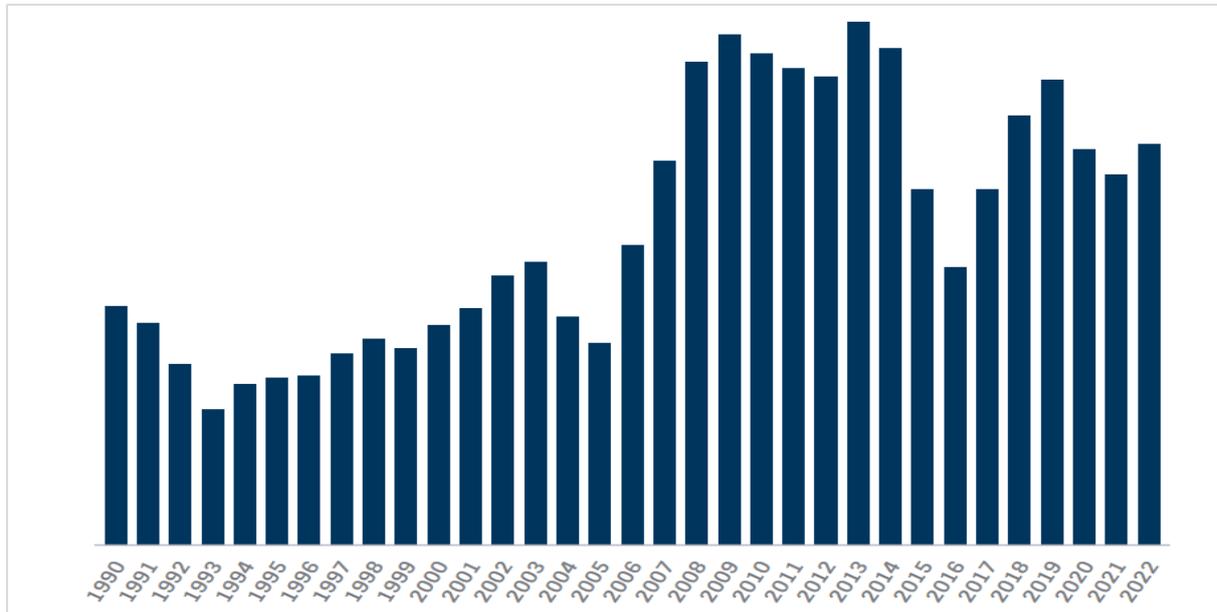
Source: Author's compilation using Vizzlo software

Gross Fixed Capital Formation (GFCF) in the mining sector has shown varying trends over the years. Between 2004/2005 and 2007, GFCF saw a significant rise due to soaring commodity prices and numerous mining projects. However, it declined during the financial crisis of 2008/2009. Recently, GFCF in the mining sector has remained low, influenced by decreased confidence, low commodity prices, and regulatory uncertainties (StatsSA, 2023).

Investing in the mining sector ensures a steady supply of essential minerals and materials needed for infrastructure and energy production. This supports the development of sustainable and reliable energy sources, reducing dependence on traditional power infrastructures and mitigating the effects of loadshedding. Furthermore, mining investments can drive the advancement of renewable energy technologies and storage solutions, enhancing the sustainability and resilience of the energy system.

2.10 Conclusion

The energy and mining sectors in South Africa are deeply intertwined, with the country's electricity supply challenges significantly impacting mining operations. Despite ambitious goals set by the National Development Plan (NDP) to diversify energy sources and ensure widespread access to electricity, South Africa continues to face severe energy shortages. Eskom, the primary electricity supplier, struggles with maintaining adequate coal reserves and managing the increasing power demand, leading to frequent loadshedding. Loadshedding, a controlled power disruption, has been a persistent issue since 2007, with its severity escalating in recent years. This has had profound effects on various sectors, particularly mining, which is highly dependent on a stable energy supply. The mining industry, a cornerstone of South Africa's economy, has seen elevated operating costs resulting from dependence on alternate energy sources such as diesel generators. This not only affects the industry's profitability but also its contribution to employment and government revenue.

The chapter highlights the historical context of electricity supply shortage, its economic implications, and the specific challenges faced by the mining sector. It underscores the need for sustainable energy solutions and policy interventions to mitigate the adverse effects of energy shortages on South Africa's economic growth and stability. The next chapter will provide a comprehensive literature review, offering insights from previous studies and theoretical frameworks relevant to electricity loadshedding.

CHAPTER THREE

LITERATURE REVIEW

3.1. Introduction

This chapter presents a literature review that examines the impact of electricity loadshedding and the significance of electricity supply on the mining sector. The first sub-section is dedicated to the theoretical framework. The theoretical framework includes a discussion of classical economics, neoclassical theory, and the Solow growth model. Each theory offers distinctive perspectives on the impact of electricity disruptions on the mining sector's productivity, efficiency, and overall economic output. The second sub-section comprises a review of empirical studies regarding the effects of loadshedding on the mining sector and other industries in South Africa as well as globally.

3.2. Theoretical framework

The theoretical framework for the influence of supply shocks on output performance is outlined in this section. These theories are general and not specifically on electricity. It can, however, be applied to electricity. Various existing theories are incorporated, examining how economic output performance is reliant on the normal functions of economics.

3.2.1. Classical economics

Classical economics, a theoretical framework established in the late 18th and early 19th centuries, provided the foundation for comprehending market dynamics, the functions of labour and capital in production, and the determinants of economic growth (Cameron, 2010). Influential economists such as Adam Smith, David Ricardo, and John Stuart Mill advanced fundamental notions such as the law of supply and demand and the production function, which remain integral to contemporary economic theory. Smith's influential treatise, The Wealth of Nations (1776), highlighted the efficacy of the market mechanism, wherein individual self-interest in a competitive environment result in the optimal distribution of resources. Ricardo enhanced the classical

framework through his theory of comparative advantage, emphasising how countries may gain from specialisation. John Stuart Mill enhanced the comprehension of capital, labour, and technological advancement in production while also examining the interplay of these elements in determining economic results (Ricardo, 1817; Mill, 1848).

3.2.1.1 Demand and supply theory

Adam Smith's theories provide valuable insights into the economic consequences of disruptions like loadshedding. While Smith did not specifically address modern challenges such as energy shortages, his foundational concepts on demand and supply, productivity, the division of labour, and the role of government can help understand the economic impacts of such disruptions.

Smith (1776) argued that individuals, driven by self-interest, make purchasing decisions based on the prices of goods and the utility they derive from consuming them. Although he did not formally articulate the law of demand as it is understood today, Smith's analysis implied that demand is influenced by both price and utility. He also highlighted that producers (suppliers) seek to maximise their profits by offering goods and services in the market. In a competitive environment, suppliers respond to price signals by adjusting their production. When prices rise, producers are incentivised to increase output, while a price drop may prompt a reduction in supply.

The mining sector is heavily reliant on electricity as a critical input for various operations, including extraction, refining, and transportation. Electricity loadshedding, or the intentional reduction of electricity supply, disrupts these processes, resulting in significant economic losses (Department of Energy, 2022). By applying basic demand and supply theories, it is possible to explore how loadshedding affects both the supply and demand for mining products, as well as its broader economic implications.

In energy-intensive industries like mining, where electricity is essential for daily operations, loadshedding disrupts the steady supply of power. This leads to a leftward shift in the supply curve as electricity shortages force mining companies to reduce production. The decreased availability of electricity raises operational costs, further diminishing output. In turn, the reduced supply causes prices to rise, as the available supply of mining products becomes scarcer relative to demand.

Disruptions in electricity supply, such as loadshedding, can influence the supply and demand curves in related markets. For instance, if electricity shortages make mining operations less consistent, the supply of raw materials (like metals) from mining companies may decline. This decrease in supply can push up the prices of these raw materials. Concurrently, industries that depend on these materials such as steel manufacturers or electronics producers might lower their demand for these inputs. In response to the higher costs or uncertain supply, these industries may seek alternatives or reduce production, which shifts the demand curve for raw materials leftward. Consequently, both the markets for raw materials and finished products (such as steel and electronics) are likely to see reduced quantities and potentially lower prices in the short term as the market adjusts to the supply and demand disruptions caused by loadshedding.

In a perfectly functioning economy, the quantity of electricity supplied would align with the demand, positively impacting industrial performance. However, in the context of South Africa and many other countries facing energy shortages, this balance is disrupted. Currently, the electricity supply is unable to meet the demand, resulting in loadshedding and affecting productivity in the mining sector. This shortage is primarily due to limited generation capacity, which constrains the supply of electricity. As a result, the energy market in South Africa is not Pareto efficient, meaning that the optimal allocation of resources is not being achieved. For the mining sector to benefit, substantial investments in electricity generation and the exploration of alternative energy sources are required. These efforts, however, may come at the expense of other sectors or stakeholders.

Muganasinghe (1979) expanded on Adam Smith's theory by developing the economics of power system reliability and planning. This theory highlights the importance of a reliable electricity supply for productivity and explores the concept of outage costs, and expenses incurred due to power failures. It suggests that even small investments in power supply can enhance efficiency and yield significant savings. Griffin and Steel (2000) define a reliable power system as one that consistently meets consumer and industrial demand. Unreliable systems fail to deliver electricity as needed, often due to unexpected supply and demand variations. Given the capital-intensive nature of the electric power sector and rising demand, substantial investments are crucial. Douglas and Dube (2002) discuss the economic costs of

unreliable electricity, which disrupts production processes that rely on electricity as an intermediate input. These costs are measured by the reduction in the present value of net social benefits. Outage costs are calculated based on the assumption that loadshedding prioritises curtailing supply to industries with the lowest output per megawatt-hour first.

3.2.1.2 Adam Smith productivity theory

Production is one of the main focuses in economics. Adam Smith (1776) asserted that capital and labour are essential inputs in production, with output dependent upon the effectiveness of their combination and utilisation. Capital denotes the machinery and tools essential for the production process, whereas labour pertains to the workforce engaged. Smith argued that capital accumulation through investments in machinery and infrastructure leads to increased productivity. He also underscored specialisation, contending that employees attain optimal efficiency when assigned precise duties.

Although Smith did not specifically address issues such as electricity loadshedding, his foundational concepts on productivity, can help understand the economic impacts of such disruptions. In the mining production context, capital encompasses the machinery, equipment, and technology utilised in extraction, refining, and transportation, while labour pertains to the humans who operate and maintain these assets. With the assumption that the mining entities rely heavily on a consistent and uninterrupted electrical supply to function their capital and improve workforce productivity, a decrease in power supply requires mining companies to make operational adjustments, frequently leading to reduced efficiency in the use of capital and labour.

During power outages, mining machinery may become inoperative, leading to reduced capital utilisation and a decrease in output per unit of capital. Similarly, labour productivity declines when employees cannot operate machinery effectively or fulfil their duties due to insufficient power. When the energy supply is inconsistent, the full potential of these investments cannot be realised, as capital-intensive machinery remains underutilised or dormant. This situation leads to diminishing returns on capital, a principle fundamental to Smith's theory.

During loadshedding, mining businesses encounter a decline in the marginal productivity of capital when machinery cannot function at full capacity, resulting in lower overall output. Applying Adam Smith's production theory enhances our understanding of productivity dynamics in this industry and the impact of issues such as loadshedding on economic efficiency.

3.2.2. The neoclassical production function

The concept of marginal productivity and the optimisation of resource allocation are introduced by neoclassical economics, which expands upon classical principles. Neoclassical theory argues that firms will utilise capital and labour until their marginal products are equivalent to their marginal costs (Marshall, 1890; Mankiw, 2021). The marginal costs of both capital and labour rise due to interruptions. Maintenance costs for capital increase, while labour productivity decreases because of these disruptions. This leads to suboptimal utilisation of these factors, ultimately reducing overall efficiency (Clark, 1899). Furthermore, the cost structures of mining companies are altered by loadshedding, which results in an increase in operational costs and a reduction in profit margins. Ultimately, this impacts the firms' competitiveness by limiting their capacity to expand operations or invest in new technologies. Neoclassical models also prioritise market equilibrium, which occurs when supply and demand are in equilibrium. This equilibrium could be disrupted by loadshedding, which reduces the supply of mined products, potentially resulting in increased prices and market inefficiencies (Mankiw, 2021).

The Cobb-Douglas production function is a widely used mathematical model in economics that describes the relationship between inputs (typically labour and capital) and the output of goods and services. The function was named after Charles Cobb and Paul Douglas who introduced it in the 1920s (Miller, 2008).

The Cobb-Douglas (1928). production function is given by the formula:

$$Y(L,K) = AL^{\beta}K^{\alpha} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.1)$$

Y= Total production (the real value of goods produced). The application of total production in this study is mining output.

L= Labour input

K= Capital input (machinery, equipment, and building)

A= Total factor productivity

$0<\alpha<1$ and $0<\beta<1$ are elasticities of labour and capital.

Key Properties of the Cobb-Douglas Production Function are:

- Constant Returns to Scale: If ($\alpha + \beta = 1$), the function exhibits constant returns to scale, meaning that doubling the inputs will double the output.
- Diminishing Marginal Returns: Each additional unit of input (capital or labour) contributes less to the output than the previous unit, assuming other inputs are held constant.
- Factor Substitutability: Capital and labour can be substituted for each other to some extent, but not perfectly (Cobb and Douglas, 1928).

The graph of the production function typically shows an upward slope, indicating that as inputs (such as machinery and equipment) increase, the output also increases:

Figure 3.1: Production function
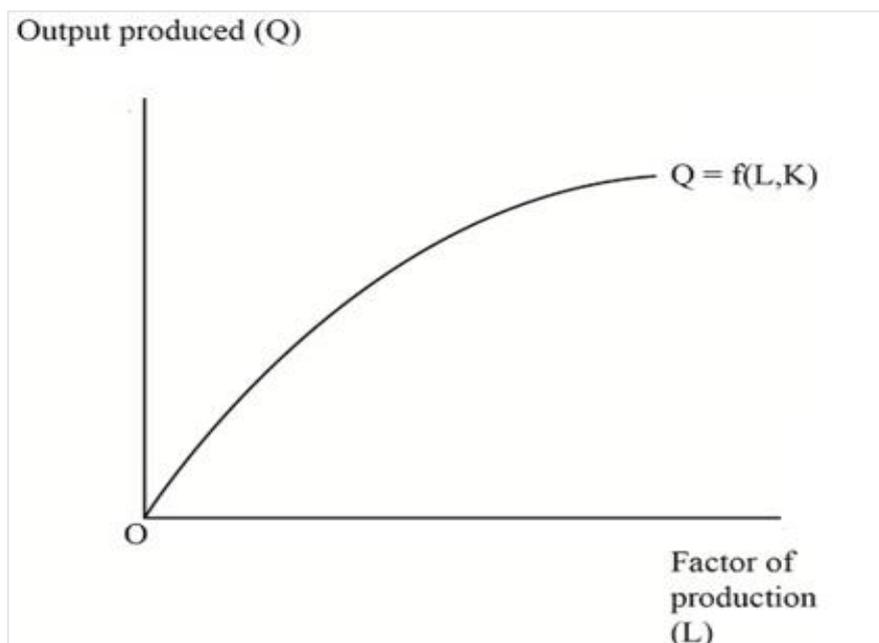
Adapted: GeeksforGeeks, (n.d.)

The graph above indicates the increasing marginal product with an upward slope. As the inputs increase, the amount of output will increase. McConnell and Brue (2005) suggest that society can boost its real output in two primary ways: by augmenting the quantity of inputs and by enhancing the productivity of these inputs. Productivity rises when workers have more and better machinery and natural resources with which to work, and the availability of electricity influences the output produced by this machinery. McDonald (2009) states that electricity is a vehicle for promoting economic growth and as such shortages in electricity could hamper economic growth. Growth theory, represented by the production possibility curve, demonstrates the maximum combinations of goods an economy can produce, given the quality of its natural, human, and capital resources, as well as its technological knowledge. Improving any of these factors will cause the curve to shift outward, signifying that a more efficient electricity supply can boost the economy's production capacity (McDonald, 2009).

Loadshedding, or planned power outages, can significantly impact the production process, particularly in energy-dependent industries. Loadshedding can reduce the effective utilisation of capital (K). Machinery and equipment that rely on electricity may become idle during power outages, leading to a decrease in production. Frequent power interruptions can cause increased wear and tear on machinery, reducing its lifespan and efficiency. Loadshedding can disrupt the workflow, leading to lower labour productivity (L). Workers may be unable to perform their tasks efficiently without a reliable power supply. Workers may experience increased idle time during power outages, reducing overall output. Firms may invest in backup power solutions or more energy-efficient technologies to mitigate the impact of loadshedding. This can affect total factor productivity (A) positively if the adaptations are effective. Companies might adjust their operational hours to align with the availability of power, which can also influence (A) (Gordon, 2011).

Industries such as the mining sector depend on electricity to operate most of their machinery. When loadshedding occurs, mining firms cannot utilise their machinery and equipment to full capacity, likely resulting in decreased output. If a firm compensates for the inability to use machinery during loadshedding by increasing labour input, it may experience a decrease in the marginal product of labour, leading to diminishing returns to scale.

3.2.3. The Solow Model

The Solow model, introduced by Robert Solow in 1956 (Jones and Vollrath, 2013), emphasises that the investment rate is one of the most important determinants of economic growth. An increase in investment leads to the accumulation of capital stock per worker, which is associated with higher per capita output. Solow also emphasised that, without technological change, economic growth would eventually stagnate due to diminishing returns to capital.

The Production Function

The Solow (1956) production function builds upon the Cobb-Douglas production function by incorporating technological advancements. This enhancement allows the model to describe more accurately how the output is generated. Typically, it is expressed as:

$$Y = A \cdot F(K, L) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.2)$$

where:

- (Y) is output,

- (A) is the level of technology,

- (K) is capital,

- (L) is labour,

- (F) is a function that combines capital and labour.

Investment and Capital Accumulation

Investment plays a crucial role in the Solow Model. It increases the capital stock, which in turn affects output. The capital accumulation equation is:

$$\Delta K = I - \delta K \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.3)$$

where:

- (ΔK) is the change in capital stock,

- (I) is investment,

- (δ) is the depreciation rate of capital.

Investment is typically a fraction of output, represented as (sY), where (s) is the savings rate. Therefore, the capital accumulation equation can be rewritten as:

$$\Delta K = sY - \delta K \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.4)$$

Steady-State and Convergence

In the long run, the economy reaches a steady state where capital per worker (k= K/L) and output per worker (y= Y/L) remain constant. At this point, investment equals depreciation:

$$sY = \delta K \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.5)$$

This implies that the economy grows at a rate determined by technological progress and labour growth.

Technological Change

Technological progress (A) is crucial for long-term growth. It elevates the production function, enabling the production of more output with the same levels of capital and labour. Technological change is often treated as an exogenous factor, meaning it is determined outside the model and grows at a constant rate (g):

$$A(t) = A_0 e^{gt} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.6)$$

where:

- (A(t)) is the level of technology at time (t),

- (A_0) is the initial level of technology,

- (g) is the growth rate of technology.

Sustained technological progress is essential for continuous growth. In this model, investment increases the capital stock, which boosts output, while technological advancements enhance productivity. When applied to electricity supply, the model suggests that investment in infrastructure, such as power plants and grids, is crucial for increasing electricity production. However, without technological improvements, such as more efficient energy generation and distribution methods, the benefits of investment will diminish over time due to the principle of diminishing returns. Therefore, sustained growth in electricity supply relies not only on continuous investment but also on ongoing technological innovation to ensure that the energy sector can meet increasing demand efficiently and sustainably. This combination of investment and technological progress is essential for a robust and reliable electricity supply that supports overall economic growth.

3.2.4 Infrastructure investment and development theory

Infrastructure investment is a crucial driving force for achieving rapid and sustained economic growth. Arrow and Kurz (1970) and Aschauer (1989) have shown that infrastructure investment, including in electricity generation and distribution, is a key determinant of national productivity. Energy enables firms to operate more efficiently, provides businesses with the resources they need to innovate, and allows workers to be more productive. A well-functioning electricity grid facilitates the smooth operation of industries, reduces business interruptions, and enhances the competitive environment. According to Srinivasu and Rao (2013), public infrastructure investment is likely to enhance a country's economic growth and development. Frischmann (2006) also emphasises the necessity for governments to allocate sufficient funds to infrastructure resources to meet national demands.

The foundational ideas of infrastructure and productivity theory can be traced back to the broader field of economic growth theory, with significant contributions from economists like Robert M. Solow. This theory suggests that investing in infrastructure, including transportation networks, energy systems, and communication technologies, is essential for enhancing the efficiency and effectiveness of production processes. By reducing transportation costs, improving market access, and facilitating the flow of

information, infrastructure investments can significantly boost productivity and, consequently, economic growth (Solow, 1987).

A key aspect of this theory is the distinction between the short-term and long-term impacts of infrastructure investments. While immediate effects might be limited due to the time required for project implementation, the long-term benefits are substantial. Infrastructure projects have the potential to transform entire economies by enabling and improving efficiencies across various sectors. These investments create a conducive environment for businesses to thrive, leading to sustained economic growth (Solow, 1956).

However, the positive relationship between infrastructure and productivity can be severely undermined by issues such as loadshedding. Loadshedding, or planned power outages, disrupts the stable power supply essential for various industries, including mining. In the context of mining production, loadshedding leads to frequent operational disruptions, causing delays and increasing operational costs. Mining equipment and machinery require a constant power supply to function efficiently, and interruptions can significantly reduce productivity.

Moreover, the costs associated with mitigating the effects of loadshedding, such as investing in backup power solutions like generators, further strain the financial resources of mining companies. These additional costs reduce profitability and can deter future investments in the sector. Safety concerns also arise, as power outages can compromise critical safety infrastructure, increasing the risk of accidents and injuries in mining operations.

3.3 Empirical Literature

This section focuses on the empirical literature and the findings of other researchers who investigated the impact of loadshedding on industry performance.

3.3.1. International Studies

Yang (2000) established a bidirectional causal link between gross domestic product and power usage in Taiwan. The study used Granger's causality tests and established

bidirectional causality between total energy consumption and GDP, suggesting that energy consumption affects and is affected by economic growth. The research also examines the causal links between GDP and several forms of energy usage, including coal, oil, natural gas, and electricity. The findings indicate that the causation direction varies among different energy sources, implying that certain types of energy use may have a more robust or tenuous correlation with economic growth. For instance, although total energy consumption demonstrates bidirectional causality, the influence of certain energy sources on GDP differs. The study underscores the essential role of energy consumption in fostering economic growth, indicating that energy deficits may impede economic performance.

The study by Bagdadee and Zhang (2019) examined the adverse effects of power quality problems on industrial activities in Bangladesh. The study employs a survey of 57 industrial consumers and mathematical models to quantify the economic effects of power interruptions. The results demonstrate that power interruptions lead to substantial economic losses and reduced productivity, forcing enterprises to implement expensive and environmentally harmful backup power alternatives, such as generators. The study underscores the imperative for improved energy-saving strategies and the execution of thorough power quality initiatives to alleviate these detrimental effects and guarantee more stable industrial operations. Masuduzzaman (2012) used the error correction model (ECM) to analyse the causal relationships between economic growth, electricity consumption, and investment in Bangladesh. The study concluded that, over time, increased electricity consumption and higher investment contribute to greater economic growth. Furthermore, the findings indicated that electricity consumption stimulates investment, and investment subsequently drives economic growth, but not the reverse.

Imilsina, Sapkota, and Steinbuks (2018) employed the CGE Model to conduct a comprehensive evaluation of the economic effects of power loadshedding in Nepal from 2008 to 2016. The employed approaches include field surveys, historical data analysis, and simulation models to evaluate the impact of power outages on several economic indicators. The study's key findings indicate that loadshedding significantly adversely affected Nepal's economy. The annual gross domestic product (GDP) decreased by an average of 6.4%. The investment landscape was significantly impacted, resulting in a 33% decline in investment demand. The industrial sector, an

essential element of economic expansion, saw a 7% decline in overall output. The reduction in production resulted in substantial declines in foreign trade, with exports and imports decreasing by 2.8% and 5.4%, respectively. The study emphasises the essential requirement for a dependable electrical supply to facilitate economic growth and lower production costs, particularly in the industrial sector. It underscores the significance of investing in resilient energy infrastructure and implementing improved electrical load management strategies. The study promotes the use of renewable energy sources, including wind and solar, in conjunction with sophisticated energy storage devices to improve electrical reliability. Furthermore, it is advisable to construct hybrid microgrid systems that integrate renewable energy sources with traditional diesel generators to guarantee a dependable power supply.

Issa, Ilinca, Rousse, Boulon, and Groleau (2023) provide an in-depth analysis of the integration of renewable energy technology and electrification in the Canadian mining industry. The study emphasises substantial prospects, including the rising investment in electric vehicle fleets for heavy-duty operations and the extensive utilisation of renewable energy in distant mining locations with prolonged operational lifespans. These innovations are essential for mitigating greenhouse gas emissions and improving energy efficiency within the mining sector. The study highlights significant hurdles, including budgetary limitations, logistical complexities, and the necessity for enhanced research and development capabilities to effectively incorporate renewable energy sources and battery electric vehicles into mining operations. The results highlight the necessity for ongoing investment and innovation in renewable energy technology to address these difficulties and attain sustainable mining operations.

Fried and Lagakos (2020) developed a dynamic general-equilibrium model to examine the effects of loadshedding on company productivity and overall economic performance in emerging nations. The model posits that the likelihood of grid power is exogenous and disregards labour input, concentrating on the impact of electricity disruptions on capital use and company production. The research indicates that an unstable electrical supply markedly diminishes business productivity by decreasing capital efficiency, thereby hindering aggregate output and economic growth. The authors emphasise that loadshedding can result in significant welfare losses, especially in energy-intensive industries such as manufacturing and mining. It is

advisable to invest in more dependable energy infrastructure, diversify energy sources, and enhance grid stability to alleviate the adverse economic impacts of power shortages and foster sustained growth.

Loadshedding in Pakistan has been thoroughly examined for its adverse impacts on industrial and economic performance. Research by Sadiq and Rehman (2018) underscores the detrimental effect of power outages on industrial productivity, especially in the textile sector, and the consequent rise in operational expenses, even with the use of backup power systems. Khan and Akhtar (2020) identified bidirectional causality between energy consumption and GDP, indicating that energy deficits impede economic growth, particularly impacting the industrial and services sectors. Shahbaz and Ahmed (2021) affirm that frequent loadshedding diminishes industrial productivity and escalates expenses in energy-intensive sectors. Jamal and Nazir (2019) indicate that power outages adversely affect GDP growth by interrupting manufacturing operations. Ali and Raza (2020) assert that frequent power shortages diminish investor trust, curtail foreign direct investment, and foster a difficult business climate, thus hindering economic progress. The literature emphasises the urgent necessity for energy reforms and diversification of energy sources to alleviate the detrimental impacts of loadshedding on Pakistan's economy and industrial productivity.

3.3.2. African countries

Zimbabwe has faced significant challenges with loadshedding, primarily due to a combination of aging infrastructure, insufficient power generation capacity, and environmental factors. The country's electricity supply has historically been unreliable, leading to frequent and prolonged power outages. Zimbabwe relies on coal-fired power plants, such as the Hwange Thermal Power Station, which are plagued by frequent breakdowns and maintenance issues, significantly reducing their output. Recent additions of 300MW units at Hwange have provided some relief, but the overall generation capacity still falls short of the country's peak demand (Kuhudzai, R. J. (2023). The economic impact of loadshedding in Zimbabwe is profound, particularly on the mining sector, which is a critical component of the economy. The Zimbabwe Chamber of Mines reports substantial losses in output and revenue due to power

outages, with the sector losing about $250 million annually (iHarare, 2023). Kasek and Hosking (2012) assessed the impact of loadshedding on the mining sector in Zimbabwe. The study revealed that loadshedding negatively impacts mines, but the extent of the effect varies between low-capacity mines and high-cost operations.

Walsh, Theron, and Reeders (2021) found that firms in electricity-intensive sectors bore the brunt of the costs associated with power outages. Similarly, Mulenga, Phiri, Kapena, and Fandamu (2016) conducted an econometric analysis on the productivity of manufacturing firms in Zambia, revealing that power disruptions negatively impact firm productivity, particularly for those without alternative electricity sources. They further discovered that firms capable of generating their electricity during periods of loadshedding experience different impacts compared to those that cannot. Firms without this capability are often forced to reduce or halt productivity.

Mukupa, Phiri, and Kunda (2018) conducted a study assessing the impact of Zambia Electricity Supply Corporation's (ZESCO) power rationing on the cost of living. Their findings indicate that although power rationing does not typically last for 24 hours, the duration of outages is long enough to negatively affect businesses and households. The lack of reliable electricity forces businesses to resort to alternative energy sources, increasing operational costs and reducing productivity. Phiri (2014) utilised cross-sectional data from the World Bank Enterprise Survey to conduct an econometric analysis of the effects of loadshedding on firm productivity in the manufacturing sector. The study revealed that loadshedding significantly reduces the productivity of manufacturing firms, with varying impacts across different sub-sectors. The agricultural sector also suffers from loadshedding, as highlighted by Kuteya (2016). This research assessed the effect of power rationing on Zambia's agricultural sector, revealing economy-wide losses amounting to ZMW 32.5 billion, representing 18.8% of the GDP. The agricultural sector alone faced losses estimated at ZMW 2.8 billion, which stifles future economic growth and affects food security.

Nduhuura, Garschagen, and Zerga (2020) and Ogbe (2014) examined the spatial distribution and effects of electricity loadshedding in Accra, Ghana. Nduhuura *et al.* (2020) utilised Geographic Information System (GIS) tools and statistical analysis to quantify neighbourhood-level loadshedding experiences during the 2015 rolling blackouts, uncovering considerable variance in annual exposure and discovering

spatial grouping patterns. Their findings underscore discrepancies in the execution of electricity loadshedding and propose that exposure maps can guide fair electrification plans. Ogbe (2014) employed a qualitative methodology, incorporating semi-structured interviews and focus group discussions, to investigate the impact of loadshedding on enterprises and homes in Accra Newtown and North Legon. The research indicates that loadshedding interrupts company functions and domestic activities, resulting in economic detriment and diminished quality of life. Ogbe (2014) sees inadequate governmental policies and the negligence of duty bearers as significant difficulties, arguing for enhanced power management and policy reforms.

Mutambo, Kawimbe, Meki-Kombe, and Mwange (2023) analysed the effects of power loadshedding on small and medium-sized enterprises (SMEs) in Tanzania, using frameworks such as resource dependence theory, institutional theory, and stakeholder theory. Their study highlights that power interruptions hinder corporate operations, leading to production delays, financial losses, and challenges in adaptability. The research used a qualitative methodology, incorporating interviews and focus group discussions to obtain insights from SMEs in Zambia. Significant findings indicate that loadshedding compels SMEs to invest in alternative energy sources, modify work schedules, and interact with stakeholders to align expectations.

3.3.3. South Africa

Economic growth has gradually been dependent on the sufficient availability and utilisation of electricity (Gawlik, Prinsloo and Ateba, 2019). Morimoto and Hope (2001) assert that the supply of electricity significantly influences economic growth. Over the past years, South Africa's electricity reserve margin has declined significantly. The net effect of this decline, in which demand outstripped supply was a growing power crisis that threatened South Africa's stated objective of growing the economy (Amusa, Amusa and Mabugu, 2009). Alam and Sarker (2010) used the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to examine causality, finding a unidirectional relationship from electricity generation to economic growth. This indicates that an increase in electricity generation boosts economic growth. Both studies demonstrate that higher electricity generation drives greater economic growth by supporting various economic activities.

Lenoke (2017) explored the impact of power cuts, electricity consumption, and electricity prices on South Africa's economy. The Engle-Granger Cointegration test analysed the long-term relationship between economic growth and energy consumption. Additionally, the Granger Causality test determined whether one-time series could predict another. The data indicates that electricity usage significantly impacts economic growth, suggesting that loadshedding negatively affects the economy. The findings highlight the importance of a reliable power supply in fostering economic growth in South Africa.

Ariel (2015) focused on the effects of loadshedding on the retail sector, highlighting the challenges faced by businesses during power outages. The research utilised a mixed-methods approach involving three separate studies. The initial study utilised qualitative semi-structured interviews with financial and operational managers in the retail sector to identify the main challenges associated with loadshedding. The second and third studies sought to quantify the costs associated with loadshedding through subjective evaluation and marginal cost of backup methodologies, respectively. The results indicated that loadshedding resulted in a significant revenue loss of R13.72 billion during the first half of 2015, while retailers allocated around R716 million toward backup power solutions in the same timeframe. This study highlights the significant impacts of unstable electricity supply on the retail sector, offering essential insights for stakeholders to effectively address the crisis.

Inglesi-Lotz and Ajmi (2021) investigated the impact of rising electricity prices and intermittent supply on Foreign Direct Investment (FDI) in South Africa, revealing how energy instability can deter international investors. The researchers employed the Autoregressive Distributed Lag (ARDL) cointegration approach to analyse data from 1985 to 2018, aiming to evaluate the long-term relationship between electricity conditions and FDI inflows. Their findings indicate that a stable electricity supply has a positive impact on foreign direct investment (FDI), whereas increasing electricity prices exerts a negative influence. This study underscores the essential function of dependable and cost-effective energy in creating an environment favourable to foreign investment, stressing the necessity for policy measures to stabilise the electricity supply and control expenses to attract and retain international investors.

Inglesi-Lotz and Mabungu (2022) examined the effects of mismatched electricity supply and demand on economic growth, emphasising the importance of balancing supply with demand. The research sought to examine the impact of imbalances between power supply and demand on economic performance. They employed an Autoregressive Distributed Lag (ARDL) model to examine data from 1985 to 2019, investigating the long-term correlations among these variables. Their findings indicated that an excess of power supply (where supply surpasses demand) favourably impacts economic growth, whereas a deficiency (where demand exceeds supply) hinders it. This research highlights the imperative of augmenting electricity supply and enhancing energy efficiency to generate a surplus that fosters economic growth. The study emphasises the essential importance of balancing power supply and demand to promote a stable and favourable environment for economic development. Oljuyin and Mago (2022) further revealed that loadshedding affects the capacity of entities to provide quality products, especially for SMMEs that do not have alternative sources of energy. However, the study investigated all industries in the economy except for the mining sector. The research examined the impact of power outages on the capacity of SMMEs to provide quality products and services, especially for those lacking alternate energy sources. The research, conducted in Gqeberha (previously Port Elizabeth), employed a qualitative methodology, including semi-structured interviews with small, medium, and micro enterprise (SMME) operators in the food sector. The purposive sample method was employed to recruit participants from the Central Business District and Summerstrand regions. The results indicated that loadshedding substantially impedes business operations, resulting in diminished customer satisfaction and subpar economic success. In response to power interruptions, numerous SMMEs utilised backup generators and implemented operational modifications. The study determined that although scheduled loadshedding permits a degree of planning, its overall effect on SMMEs is adverse, underscoring the necessity for a dependable power supply to ensure economic survival.

The reviewed studies repeatedly emphasise the essential role of a reliable and adequate energy supply in promoting economic growth in South Africa. The detrimental impact of loadshedding on many sectors, such as retail and small to medium-sized enterprises (SMMEs), highlights the critical necessity for dependable

power to maintain economic operations and attract foreign investment. The study highlights the necessity of equilibrating power supply and demand to foster a climate suitable for economic development.

A significant gap exists in the literature regarding the effects of loadshedding on the mining sector. Considering the mining industry's substantial impact on South Africa's economy, additional research is important to comprehend how power interruptions influence this sector's productivity and overall economic performance. Addressing this gap could yield useful information for policymakers and stakeholders to formulate targeted solutions that alleviate the adverse effects of electrical volatility on the mining sector and, consequently, the wider economy.

The literature study emphasises the essential importance of electricity supply in promoting economic growth, with multiple studies highlighting the substantial influence of power availability and stability on diverse economic sectors. The diminishing electrical reserve margins and the rising incidence of loadshedding in South Africa have presented significant obstacles to economic growth and stability. Research conducted by Amusa, Amusa, and Mabugu (2009), as well as Inglesi-Lotz and Mabungu (2022), highlights the adverse impacts of energy shortages on economic activities and foreign direct investment. Studies from other African nations, including Zimbabwe and Zambia, further demonstrate the extensive economic impacts of power outages, especially on critical industries such as mining and manufacturing. The results of this research collectively highlight the critical need for a reliable and adequate electrical supply for economic growth and stability. Although considerable research has been undertaken regarding the effects of power supply and loadshedding on different economic sectors, a significant gap exists in the literature concerning the potential impacts of loadshedding on the mining sector in South Africa. Previous research, including works by Lenoke (2017) and Ariel (2015), has investigated the overarching economic implications and sector-specific influences; nevertheless, the mining sector, an essential element of South Africa's economy, has not been comprehensively analysed in this regard.

3.4 Conclusion

Chapter three highlights the critical role of a reliable electricity supply in promoting economic growth, particularly within the mining sector. The effects of electricity loadshedding on industrial production are clear, leading to decreased output and increased operational costs. The detrimental impact of power outages on productivity and economic efficiency is illustrated through theoretical frameworks such as the Cobb-Douglas production function and the Solow Model. Empirical research conducted in South Africa and other African countries emphasises the negative consequences of an inconsistent electricity supply in various sectors, especially mining.

While extensive research has investigated the effects of power supply and loadshedding across different economic sectors, there is a significant gap in the literature regarding the specific impacts of loadshedding on the mining sector in South Africa. Although previous studies have addressed the broader economic implications and specific influences across various sectors, a thorough examination of the mining sector, an essential component of South Africa's economy, remains lacking. Addressing this gap is vital for developing targeted strategies to mitigate the adverse effects of loadshedding and support continued economic development. The next chapter will outline the approach taken to address this gap, including a detailed account of the research design, data collection methodologies, and analytical tools used to investigate the effects of loadshedding on the mining industry in South Africa.

CHAPTER FOUR

RESEARCH DESIGN AND METHODOLOGY

4.1. Introduction

In the previous chapter, a review of the existing literature on the impact of electricity loadshedding on various sectors was presented. The review highlighted the significant challenges and disruptions caused by shortage in electricity supply, particularly in energy-intensive sectors such as mining. The literature also underscored the economic implications of power outages, providing a critical foundation for understanding the broader context of this study.

Building on the insights from the literature review, this chapter outlines the research methodology employed to achieve the study's objectives. The primary aim of this research is to investigate the impact of supply shocks on the mining sector in South Africa. Several key objectives are structured around this aim. The analysis of how fluctuations in electricity supply affect production levels in the South African mining sector, both in the short run and the long run, is conducted. To address this objective, the methodological framework adopted for the study is outlined. The key variables relevant to the South African context, including electricity supply metrics, mining production data, and total factor productivity figures, are defined. The analytical models used to analyse the data are detailed. These models are selected based on their suitability for capturing the dynamic relationship between electricity supply and mining sector performance. Both econometric and statistical techniques are employed to provide an understanding of the impacts.

4.2 Research Design

As outlined by Sileyew (2019), a research design is defined as a detailed plan of how research will be conducted. It encompasses methods for data collection, instruments to be utilised, and procedures for analysing the collected data. In this study, a correlational research design is primarily followed. This design examines the links among two or more variables without exerting control or manipulation over them. The

extent to which variables are related is measured, uncovering interactions, and allowing predictions based on these relationships (Research Method, n.d.).

The nature of this study is quantitative, and time series analysis is employed to achieve the study's objectives. The impact of shortage of electricity supply on the mining sector is investigated through this research design. To achieve the proposed objectives, the Johansen cointegration test is utilised to examine the long-term relationships between variables. Furthermore, the Vector Error Correction Model (VECM) is employed, and diagnostic tests are employed to detect serial correlation and heteroscedasticity in time series data. Furthermore, stability tests are performed to verify the correct specification of the model.

4.3. Data sources and sampling

This study employs secondary annual time series data spanning from 1990 to 2022, resulting in 33 observations. This timeframe was chosen based on the availability and consistency of data across all variables examined. The use of 33 annual observations provides a sufficient sample size for time series analysis, allowing for the identification of long-term trends, structural shifts, and meaningful relationships among variables.

The variables selected include electricity generated and available for distribution, Gross Domestic Product (GDP), Mining Production (MP), Gross Fixed Capital Formation (GFCF) in mining and quarrying, and Total Factor Productivity (TFP). These variables are commonly used in the literature to assess economic growth, sectoral performance, and productivity. Electricity generated or available for distribution serves as a proxy for energy supply shocks, reflecting the supply side of the electricity market. When electricity generation or distribution declines, it often indicates that supply is insufficient to meet demand, resulting in loadshedding. In this study, data points below the annual mean of electricity supply are interpreted as indicative of loadshedding periods. This approach allows for the identification of patterns and severity of electricity supply disruptions over time, providing insight into their impact on mining performance and broader economic indicators.

The datasets for GDP and mining production are obtained from Statistics South Africa (StatsSA). Data on Gross Capital Formation in mining and quarrying is sourced from the South African Reserve Bank (SARB). Since data from South African institutions is

unavailable, the total factor productivity (TFP) data is acquired from the Organisation for Economic Co-operation and Development (OECD). These institutions provide timely, accurate, and accessible official statistics. A common technique for handling negative values is to add a constant value to the data prior to applying the log transform. This method has been applied to ensure the data is suitable for the transformation

4.4 Model specification

Inglesi-Lotz and Mabungu (2022) investigated the impact of imbalances between electricity supply and demand on economic growth, highlighting the need for equilibrium. They utilised an Autoregressive Distributed Lag (ARDL) model to analyse data from 1985 to 2019, focusing on variables such as electricity generated, electric power consumption, trade openness, gross fixed capital formation, GDP, and employment. Their study provides a foundational model that can be tailored to the mining sector in South Africa.

The model consists of five variables with annual time series data. These variables include electricity produced or available for distribution in South Africa, which serves as a proxy for loadshedding by measuring the amount of electricity generated and available for consumption, mining production and economic growth. In the model, mining production is regarded as the dependent variable, while economic growth, electricity produced for distribution in South Africa, and gross fixed capital formation in mining and quarrying are considered independent variables. The equation of this model can be expressed as follows:

$$MP = f(ED, GDP, GFCFM, TFP)\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.1)$$

$$MP_t = \beta_0 + \beta_1 ED_t + \beta_2 GDP_t + \beta_3 GFCFM_t + \beta_4 TFP_t + \mu_t\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.2)$$

To standardise the variables to be in the same format or the same unit of measure, the variables will then the logged. Equation 2 is then represented as

$$MP_t = \beta_0 + \beta_1 LED_t + \beta_2 LGDP_t + \beta_3 LGFCFM_t + \beta_4 LTFP_t + \mu_t\dots\dots\dots\dots\dots\dots\dots (4.3)$$

Where:

RGMP   = Real growth in mining production

ED   = Electricity generated and available for distribution in South Africa

GDP   = Gross domestic product

GFCFM   = Gross Fixed Capital Formation: Mining and quarrying

TFP   = Total factor productivity (TFP)

μ   = Stochastic disturbance term

Subscript t indicates the utilisation of time series data in the study, and the Betas are the parameters to be estimated, and L is the logarithm operator.

4.4.1 Discussion of variables and their expected signs of impact

Table 4.1 provides a description of each variable, details the sources of the data, specifies the units of measurement, and indicates the anticipated signs. This approach aims to enhance the clarity and robustness, enabling a more precise and meaningful interpretation of the results.

Table 4.1: Definition of variables and expected signs.

Variable Name	Variable Symbol	Full Description	Unit of Measure	Source	Expected Sign
Mining Production	MP	It captures the gross value added by the mining industry	Percentage	Statistic South Africa (StatsSA)	Not applicable as it is the dependable variable
Electricity produced or available for distribution	ED	The total electricity supplied by Eskom in South Africa	Gigawatt hour	Statistic South Africa (StatsSA)	Positive/Negative
Gross Domestic Product	GDP	The market value of goods and services produced within a country, usually over a period of one year	South African Rands	Statistic South Africa (StatsSA)	Positive/Negative
Total Factor productivity	TFP	Compares total outputs relative to the total inputs used in production of the output	Index	OECD	Positive
Gross fixed capital formation: mining and quarrying	GFCFM	Improvements of land and purchases of and construction of capital equipment such as power plants	South African Rands	South African Reserve Bank (SARB)	Positive

Source: Author's compilation

4.5. Estimation techniques

The auto-regressive distributed lag (ARDL) model is employed in the study. In the ARDL model, the dependent variable is a function of its historical values (autoregressive) and the present and historical values of other variables (distributed lag). The model accommodates variables that are stationary, nonstationary, or a combination of both. None of the variables included in the ARDL model should be integrated into order 2, I (2). The ARDL model, in its equilibrium correction (EC) form, distinguishes between long-run and short-run effects and assesses cointegration or, more broadly, the presence of a long-run link among the variables. The ARDL models can accept various lag structures, including static regressions as specific instances (Kripfganz and Schneider, 2018).

The general form is:

$$y_t = \mu + \sum_{k=1}^{p} \rho k \, y_{t-k} + \sum_{j=0}^{q} \beta_j \, x_{t-j} + \varepsilon_t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.4)$$

where y represents the dependent variable, and x denotes an explanatory variable. The static model occurs when p equals 0 and q equals 0.

4.6 Estimation procedures

A variety of procedures are carried out, including providing descriptive statistics, executing unit root tests using the Augmented Dickey-Fuller and Phillips-Perron methods, determining lag length according to five information criteria, conducting cointegration tests and error correction, and performing variance decomposition and impulse response analysis.

4.6.1 Descriptive statistics and pairwise correlation

Descriptive statistics, as highlighted by Yellapu (2018), are typically presented in tables to illustrate relationships between variables. This step is crucial in research, especially when making inferential statistical comparisons. These tables summarise data by including metrics such as the mean, standard deviation, sample size, and

significance levels for correlations. Understanding descriptive statistics is essential for grasping the data's characteristics and correlations with other variables.

4.6.2 Unit root test

The purpose of unit root testing is to determine the stationarity and order of integration of variables. It classifies series as stationary or non-stationary (Sjo, 2008). Nielsen (2005) emphasises the importance of identifying whether a process has an attractor for effective forecasting. Variables exhibit stationarity when their mean, variance, and autocovariance remain constant across all specified lag orders. Consequently, using a non-stationary series can result in misleading regression outcomes (Mongale and Noumbissies, 2014). Stationary variables enable the differentiation between the long-run and short-run effects of the model.

This study utilises both informal and formal methodologies for unit root testing. The informal approach, referred to as visual inspection, relies on graphical representations of the variables being analysed. As noted by Gujarati and Porter (2009), before conducting a formal test, it is prudent to graphically plot the time series being examined. These plots provide preliminary insight into the characteristics of the series. The formal testing is conducted using the Augmented Dickey-Fuller (ADF) and Philip Perron (PP) tests.

The Augmented Dickey-Fuller (ADF)

The ADF test thumb rule states that the data is considered stationary if the probability value falls below the 5% significance level or when the critical values are less than the t-statistic at various significance levels. The equation for ADF is expressed as follows:

$$\Delta y_t = \alpha_0 + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + \ldots + \delta_{p-1} \Delta y_{t-p+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (4.5)}$$

where α represents the constant term, β is the coefficient on the time trend, and ρ denotes the lag order of the autoregressive process. The optimal lag length for the

model is determined by maximising the log-likelihood function (Maggiora and Skerman, 2009).

Philips Perron (1988)

The Phillips-Perron (PP assesses the stationarity of variables. It introduces a nonparametric method to control for serial correlation, eliminating the need for augmentation. The test statistics can adjust the Augmented Dickey-Fuller test to account for serial correlation and correct for heteroscedasticity (Phillips and Perron, 1988).

The Phillips-Perron (PP) test involves estimating the following regression:

$$\Delta Yi = \alpha + Pyi-1 + \alpha Yt-1 + \varepsilon .... \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4.6)$$

4.6.3 Lag length selection criteria

Lag length selection is a crucial step in time series modelling, in when constructing autoregressive models (AR), vector autoregressions (VAR), or error correction models (ECM). The choice of the optimal lag length significantly affects the results, forecasts, and inferences of the model. Several criteria are commonly used to select the optimal lag length. These include information criteria such as the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Hannan-Quinn Information Criterion (HQIC), as well as statistical tests like the Likelihood Ratio (LR) test and the F-test. (Shibata, 1980).

4.6.4 Cointegration test

The Johansen cointegration approach is employed in the study to identify long-run relationships among the variables. As noted by Gujarati (2004), the method begins with the Vector Autoregression (VAR) representation of the variables.

$$\Delta Y_t = \mu + \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_j \Delta Y_{t-1} + \varepsilon_1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(4.7)}$$

where Y_t is an $nx1$ vector of variables that are integrated of order of one, commonly denoted by I (1) and ε_t is an $nx1$ vector of innovations. If the coefficient matrix Π has a reduced rank r<n, then there exist nxr matrices α and β each with rank r such that $\Pi = \alpha\beta^1$ and $\beta^1 Y_t$ is stationary, whilst r is the number of cointegrating relationships.

The Johansen cointegration approach relies on two likelihood ratio tests to determine the reduced rank of the matrix: the trace test and the maximum eigenvalue test. The Trace test is given by:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} 1n(1 - \hat{\lambda}_{r+1}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(4.8)}$$

The maximum eigenvalue test is given by:

$$\lambda_{max} = -T1n(1 - \hat{\lambda}_{r+1}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(4.9)}$$

where:

T is the sample size, and $\overset{I}{\overset{\Lambda}{\lambda}}$ is the *ith* largest canonical correlation.

β^1, denotes the matrix of cointegrating vectors.

α, signifies the speed of adjustment coefficients.

r, indicates the number of cointegrating relationships.

Π, defines the degree of cointegration within the system and is referred to as the impact.

The hypothesis is stated as:

H0: There is no cointegration among the variables.

H1: The variables exhibit cointegration.

If the Trace or Max-Eigen statistic is greater than the 0.05 critical value, the null hypothesis is rejected, suggesting that there is cointegration among the variables. On the other hand, if the calculated statistic is below the critical value, we fail to reject the null hypothesis, indicating the absence of cointegration among the variables.

4.6.5 The Vector Error Correction Model (VECM)

The vector error correction model (VECM) aims to identify the short-run relationships between the variables. The VECM is applied only if the Johansen cointegration test confirms cointegration among the variables.

Model specification:

$$\Delta X_t = \beta_{x0} + \beta_{xx1}\Delta_{t-1} + \beta_{x11}\Delta P^1{}_{t-1} + \beta_{x21}\Delta P^2{}_{t-1} + v^x{}_t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(4.10)$$

$$\Delta P^1{}_t = \beta_{10} + \beta_{1x1}\Delta_{t-1} + \beta_{111}\Delta P^1{}_{t-1} + \beta_{121}\Delta P^2{}_{t-1} + v^1{}_t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(4.11)$$

$$\Delta P^2{}_t = \beta_{20} + \beta_{2x1}\Delta_{t-1} + \beta_{211}\Delta P^1{}_{t-1} + \beta_{221}\Delta P^2{}_{t-1} + v^2{}_t \dots\dots\dots\dots\dots \dots\dots \dots(4.12)$$

$$\Delta P^3{}_t = \beta_{30} + \beta_{3x1}\Delta_{t-1} + \beta_{311}\Delta P^1{}_{t-1} + \beta_{321}\Delta P^2{}_{t-1} + v^3{}_t \dots\dots\dots\dots\dots\dots\dots\dots\dots.. \dots.(4.13)$$

$$\Delta P^4{}_t = \beta_{30} + \beta_{4x1}\Delta_{t-1} + \beta_{411}\Delta P^1{}_{t-1} + \beta_{421}\Delta P^2{}_{t-1} + v^{34}{}_t \dots\dots\dots\dots\dots\dots\dots\dots\dots..(4.14)$$

Where: ΔX_t represent the growth in mining production, $\Delta P^1{}_t$ represent the economic growth and $\Delta P^2{}_t$ represent the electricity generated in South Africa and $\Delta P^3{}_t$ is gross fixed capital formation: mining and quarrying. β Represent the coefficients of the variables, $t-1$ represent the tests for unit root, while $(v^x{}_t, v^1{}_t, v^2{}_t)$ represents the VECM error terms.

The Error Correction Term (ECT) measures the speed at which a variable return to equilibrium following an economic shock, along with the extent and direction of this adjustment. Typically, the ECT is expected to have a negative sign, suggesting that the variable is adjusting downward towards equilibrium.

4.6.6 The Impulse Response Function and Variance decomposition analysis

Impulse response and forecast error variance decomposition analysis are crucial tools for assessing both linear and nonlinear multivariate time series models (Lanne and Nyberg, 2016). The key distinction between the impulse response function and variance decomposition, including their generalised versions, lies in how shocks are interpreted: in the impulse response function, shocks are uncorrelated and have economic significance, while in variance decomposition, each shock is linked specifically to one equation within the model.

The impulse response function shows how the present and future values of each variable react to a one-unit increase in the current value of one of the VAR errors. It captures the impact of an exogenous shock on the system over time. Specifically, the impulse response function demonstrates how electricity generation and availability adjust over time in response to industrial production, especially in the mining sector.

4.7 Diagnostic test

The purpose of the diagnostic tests is to ensure that the linear regression provides accurate estimates. This process begins with the Jarque-Bera test, which assesses whether the residuals are normally distributed (Gujarati and Porter, 2009). The Breusch-Godfrey, Breusch-Pagan-Godfrey, and ARCH tests will also be used to detect serial correlation and heteroskedasticity.

4.7.1 Multicollinearity

Multicollinearity violates the assumptions of the Classical Linear Regression Model, which states that explanatory variables should not be correlated (Gujarati and Porter, 2009). Multicollinearity occurs when there are very high inter-associations among the independent variables. The Variance Inflation Factor (VIF) procedure is used to assess the severity of multicollinearity. A VIF value greater than 10 indicates a potential concern, and the goal is to achieve a VIF less than 10.

4.7.2 Heteroscedasticity

In the classical Linear Regression Model, the error term's variance should be constant, implying homoscedasticity, where the disturbances have equal variance. Heteroscedasticity arises when this assumption is violated, meaning the error term's variance changes across different values of the independent variable. The null hypothesis assumes homoscedasticity, indicating that the residuals' variance remains constant across all levels of the predictor variable. The alternative hypothesis suggests heteroscedasticity, meaning the variance of the residuals varies with the levels of the predictor variable. The Breusch-Pagan test is employed to detect heteroscedasticity.

4.7.3 Serial correlation

Serial correlation, or autocorrelation, violates the classical assumption that error terms are uncorrelated. It suggests that the disturbance term from one time period is systematically related to the error term from another period (Gujarati and Porter, 2003). The null hypothesis assumes no serial correlation, meaning the errors are uncorrelated, while the alternative hypothesis indicates the presence of serial correlation, implying correlated errors. Tests used for detecting serial correlation include the Correlogram Q-statistic test and the Breusch-Godfrey test.

4.7.4 Normality test

Normality is an important assumption in regression analysis. A normality test evaluates whether the data come from a normally distributed population, confirming that the data used in the analysis follow a normal distribution. The Jarque-Bera test is used to assess whether the distribution of the data significantly deviates from normality, based on parameters such as the p-value. If the p-value is below 0.05, it suggests a significant deviation from normality.

4.7.5. Model Stability

Various tests utilising recursive residuals are employed to assess the structural integrity of the model. The two most significant are the CUSUM and the CUSUMSQ. The primary objective of conducting this test is to uncover parameter instability, detect structural fractures, and assess the temporal stability of a model's parameters. If the CUSUM or CUSUMSQ plot remains within the two crucial lines, the model is considered stable. A poorly defined error correction model may cause misspecification bias and inappropriate functional forms, leading to an inflated R^2. Hence producing misleading results (Asteriou and Hall, 2011).

4.8. Conclusion

In this chapter, an overview of the research methodology employed to investigate the impact of electricity loadshedding on the mining sector in South Africa is provided. A correlational research design is primarily followed, utilising secondary annual time series data from 1990 to 2022. Key variables such as electricity supply, mining production, GDP, and total factor productivity are analysed using econometric and statistical techniques, including the Johansen cointegration test and the Vector Error Correction Model (VECM). The data sources, sampling methods, and specific models used to interpret the data are detailed. The Auto-Regressive Distributed Lag (ARDL) model is employed to capture both short-run and long-run effects, while various diagnostic tests are conducted to ensure the robustness and reliability of the results. It is expected that the findings from these analyses will provide a nuanced understanding of how electricity loadshedding affects the mining sector's performance, contributing valuable insights for policymakers and stakeholders in the South African mining industry.

CHAPTER FIVE

REPORTING, INTERPRETATION, AND DISCUSSION OF RESULTS

5.1 Introduction

In this chapter, the study presents the results and findings of the study. The overarching objective of the study is to determine the implication of electricity supply shocks on the mining sector in South Africa. The null hypothesis of the study states that supply shocks have no significant impact on the mining sector in South Africa while the alternative hypothesis states that loadshedding has a significant impact on mining sector in South Africa. The decision to reject the null hypothesis is determined by the findings of the results as well as by empirical evidence.

The ARDL bounds test method is used to empirically estimate the regression model. Section 5.2 provides descriptive statistics of the analysed variables, followed by an examination of their stationarity in Section 5.3, using a unit root test to determine the integration order of each variable. Section 5.4 presents the ARDL bounds test results, the error correction model, and the diagnostic test results.

The study's results are generated using EViews 13 software, utilising annual time series data from 1990 to 2022, covering both the pre-loadshedding period (before 2007) and the re-emergence of loadshedding (2018) in South Africa.

5.2 Descriptive statistics

This section explains the characteristics of each variable. Table 5.1 depicts the characteristics of the dependent and independent variables, which are mining production (MP), electricity available for distribution (ED), GDP, Gross Fixed Capital Formation: mining (GFCFM), and total factor productivity (TFP).

Table 5.1 Summary of descriptive statistics

	MP	L_ED	GDP	L_GFCFM	L_TFP
Mean	-0.32424	9.75120	2.15495	10.35238	0.06167
Median	-0.90000	9.82087	2.60000	10.38665	0.06985
Maximum	11.60000	9.90809	5.60381	11.65872	0.13769
Minimum	-10.40000	9.44363	-5.96336	8.72177	-0.03483
Std.Dev.	4.02081	0.14877	2.44311	0.99967	0.04728
Skewness	0.19092	-0.86390	-1.20372	-0.21484	-0.43655
Kurtosis	4.59890	2.38109	4.98279	1.48016	2.23627
Jarque-Bera	3.71565	4.63151	13.37486	3.42998	1.85019
Probability	0.15601	0.09869	0.00125	0.17997	0.39649
Sum	-10.70000	321.78960	71.11330	341.62860	2.03515
Sum Sq.Dev.	517.34060	0.70820	191.00050	31.97873	0.07153
Observations	33	33	33	33	33

Source: Author's compilation from EViews 13

The statistical analysis of the variables reveals variations in mean values, with the standard deviations differing across the variables. The data set is systematically distributed when the skewness value is between -0.5 and 0.5. The skewness values are generally close to zero but slightly negative. This shows that GDP and ED are moderately negatively skewed, while MP, GFCFM, and TFP are nearly symmetric. The kurtosis indicator is mostly around two and four, except for the GFCFM. The Jarque-Bera rejection rule states that the null hypothesis is rejected when the p-value is less than or equal to 0.05. In this case, the estimated Jarque-Bera probability value generally confirms a normal distribution for all variables, with the exception of GDP.

5.3 Unit root testing

Unit root testing consists of both the informal unit root (line graph) and the formal unit root (ADF and PP)

5.3.1 Informal unit root testing

Figure 5.1: GDP at level form and first difference (Differenced GDP)
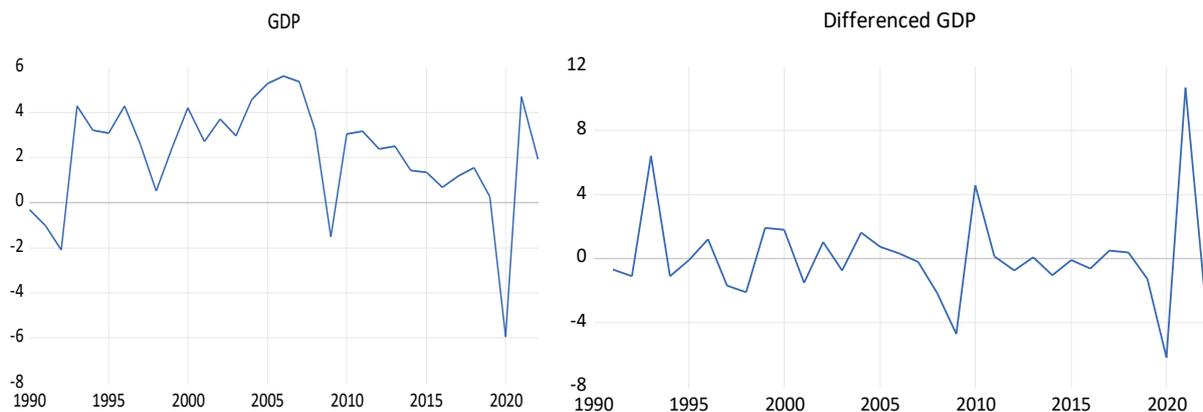
Source: Author's computation from EViews 13

The GDP does not appear to be stationary in Figure 5.1(a) since the mean does not linger near zero on the X-axis. However, after being differenced once (Differenced) in (b), GDP seems to become stable. This is indicated by a mean hovering near zero on the X-axis, indicating stationarity.

Figure 5.2: L ED and first difference (Differenced L ED)
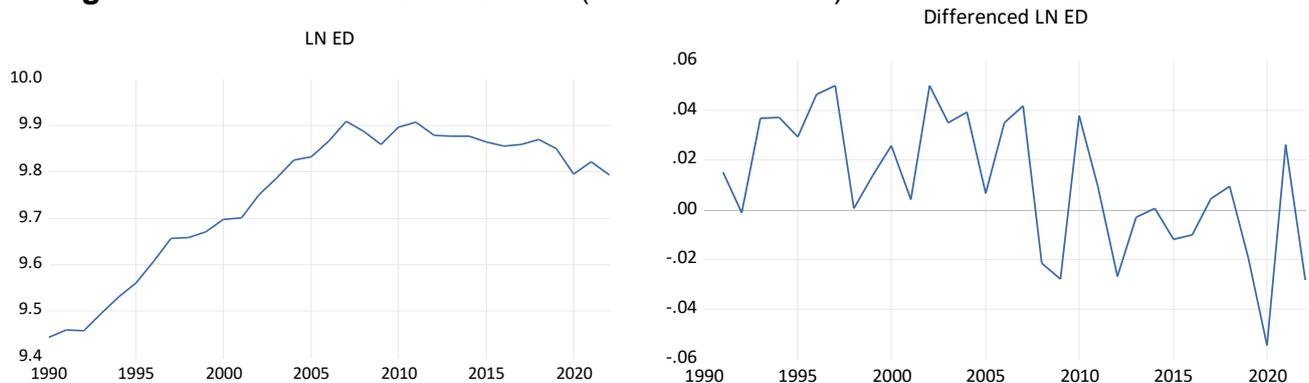
Source: Author's computation from EViews 13

LN ED does not appear to be stationary in Figure 5.2(a) since the mean does not linger near zero on the X-axis. The figure is also showing an upward trend and starts to stabilise around 2007 onward. However, after being differenced once (Differenced) in (b), LN ED seems to become stable. This is indicated by a mean that is hovering near zero on the X-axis, indicating stationarity.

Figure 5.3: L GFCFM and first difference (Differenced L GFCFM)
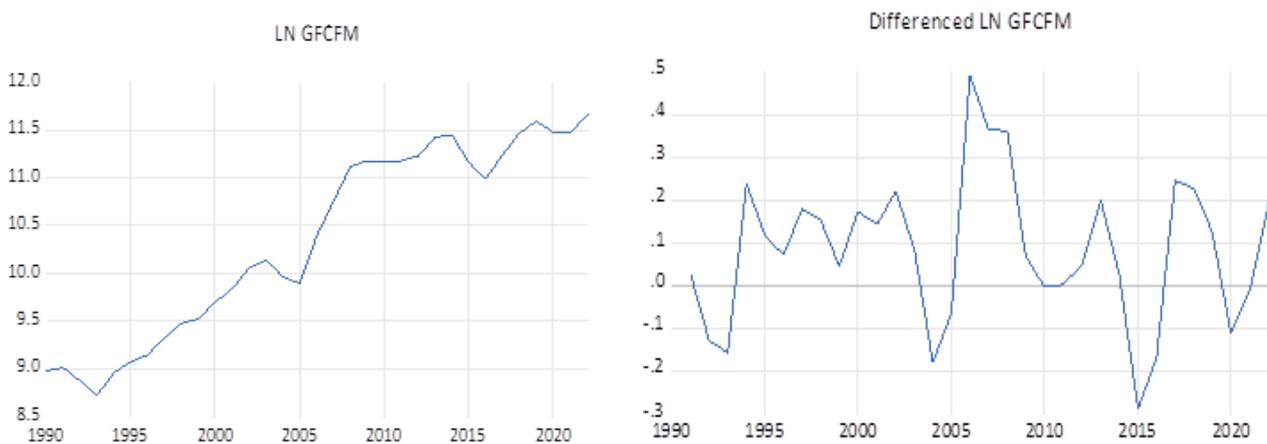
Source: Author's computation from EViews 13

L GFCFM in Figure 5.3 (a) does not seem be stationary because the mean does not hover around zero on the X-axis: instead, the figure shows an upward trend throughout the period, meaning the mean is increasing over the period. However, L GFCFM becomes stationary after being differenced once (Differenced L GFCF) in (b). This can be noted by a mean that hovers around zero on the X-axis which therefore indicates stationarity.

Figure 5.4: MP and first difference (Differenced MP)

MP

Differenced MP
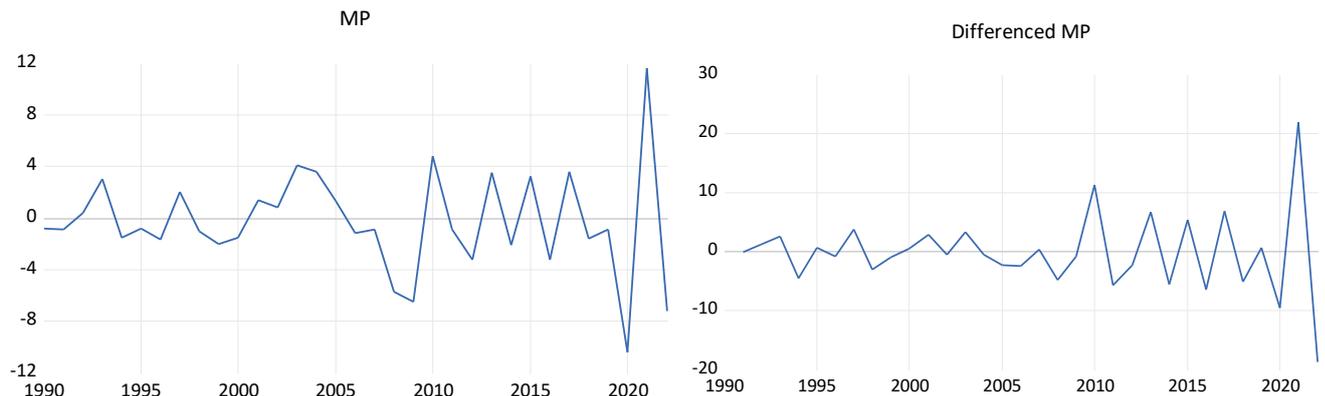
MP in Figure 5.4(a) seems to be somewhat stationary as the mean hovers around zero on the X-axis. However, for some periods, the mean seems too far from zero. However, MP becomes stationary across all years after being differenced once (Differenced MP) in (b). This is evidenced by a mean that remains near 0 on the X-axis, indicating stationarity.

Figure 5.5: L TFP and first difference (Differenced L TFP)

LN TFP

Differenced LN TFP
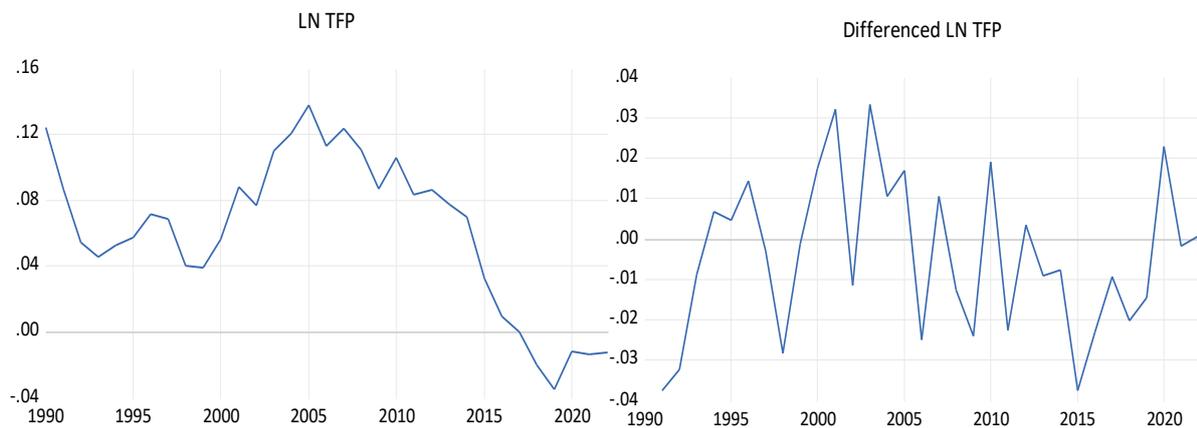
L TFP in Figure 5.5 (a) does not seem to be stationary because the figure shows an upward trend before 2005 and a downward trend after 2005. The mean does not hover along zero on the X-axis which means the mean across the period is not constant. However, L TFP becomes stationary after being differenced once (Differenced LTFP)

in (b). This can be noted by a mean that hovers around zero on the X-axis which therefore indicates stationarity.

5.3.2 Formal unit root testing

The unit root test is necessary for the study since it is a prerequisite for ARDL model. The ARDL model necessitates that variable be integrated into order zero, I (0), or order one, I (1), or a mix thereof. Second-order variables, I (2), should remain unintegrated.

Table 5.2 Unit root test results

Variables	Model	ADF		PP	
		Level	Differenced	Level	Differenced
MP	Intercept	-3.288**	-6.502*	-2.541	-8.341*
	Trend and Intercept	-4.863*	-6.467*	-3.201	-8.969*
L ED	Intercept	-2.913***	-3.976**	-2.742	-4.221*
	Trend and Intercept	0.151	-6.031*	0.563	-5.984*
GDP	Intercept	-3.581**	-5.593*	-3.606**	-7.023*
	Trend and Intercept	-3.558**	-6.012*	-3.558**	-6.998*
LGFCFM	Intercept	-0.902	-5.313*	-0.481	-4.138*
	Trend and Intercept	-1.48	-5.275*	-1.939	-5.038**
L TFP	Intercept	-1.004	-4.976*	-1.303	-4.969*
	Trend and Intercept	-1.225	-4.974*	-1.528	-4.967*

Source: Author's computation from EViews 13

* Rejection at 10% level of significance

** Rejection at 5% level of significance

*** Rejection at 1% level of significance

Table 5.2 display the detailed results as well as the sequence of variable integration. The ADF and PP test results indicate that the variables MP and GDP are stationary at level I (0). L ED is stationary at a level according to the ADF test but requires first differencing I (1) according to the PP test. L GFCFM and L TFP are not stationary at

level but become stationary after first differencing I (1) in both tests. These results suggest that while some variables are inherently stable over time, others need to be differenced to remove trends and achieve stationarity, which is crucial for reliable time series analysis. Consequently, the ADF test is preferred for these variables. According to the test statistics, the findings are a combination of stationary at level I (0) and/or first difference I (1), but none of the variables are I (2). As a result, applying the ARDL bounds test is a legitimate option.

Based on the results, proceeding with the ARDL model is appropriate. This model is suitable because it requires variables to be integrated into order zero I (0), order one I (1), or a mix of both. Importantly, none of the variables are integrated into order two I (2), confirming the ARDL model's suitability for the analysis. The data satisfies the prerequisites for using the ARDL model, enabling effective examination of the long-term and short-term relationships between the variables.

5.4 Lag length selection criteria

The results of the Johansen cointegration tests, which include both the trace and maximum eigenvalue tests, is determined using the lag length of 1 as shown in Table 5.3.

Table 5.3: Lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-50.958	NA	2.54E-05	3.610195	3.841483	3.685589
1	76.23446	205.1492*	3.57e-08*	-2.982869*	-1.595139*	-2.530503*
2	100.1885	30.90844	4.38E-08	-2.915388	-0.371217	-2.086051

Source: Author's compilation from EViews 13

At lag 0, this model has the highest FPE (2.54E-05) and AIC (3.610195), while at Lag 1, the model has the lowest FPE (3.57e-08) and AIC (-2.982869), suggesting it is the best model according to these criteria. The likelihood ratio (LR) test statistic is also significant (205.1492*), indicating that adding one lag improves the model significantly. At lag 3 the model has a slightly higher FPE (4.38E-08) and AIC (-2.915388) compared

to the lag 1 model, it is still better than the lag 0 model. However, the improvement over the lag 1 model is not as significant. Overall, the model with 1 lag is preferred based on the lowest AIC, SC, HQ, and FPE values, indicating the best fit for the data.

5.5: Cointegration tests

Based on the cointegration test results in Table 5.4, the null hypothesis of no cointegration is rejected when the computed trace statistic exceeds the critical value. The trace test results in Table 5.4 indicate that for "At none," "At most 1," and "At most 2," the trace statistic values are higher than the critical value at the 0.05 significance level. Consequently, the null hypothesis is rejected, confirming the presence of cointegration. The trace test identifies three cointegration equations at the 0.05 significance level.

Table 5.4: Trace test

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.** Critical Value
None*	0.74919	93.81015	69.81889	0.00020
At most 1*	0.49199	50.93541	47.85613	0.02500
At most 2*	0.43653	29.94072	29.79707	0.04810
At most 3*	0.28980	12.15787	15.49471	0.14950
At most 4	0.04875	1.54936	3.84147	0.21320

Source: Author's computation from EViews 13

* Rejection at the 0.05 level

Table 5.5: Max-eigen statistic

Unrestricted Cointegration Rank Test (Max-eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.** Critical Value
None*	0.74989	41.87474	33.87687	0.0033
At most 1	0.49199	20.99469	27.58434	0.2765
At most 2	0.43653	17.78285	21.13162	0.1382
At most 3	0.28980	10.60850	14.26460	0.1750
At most 4	0.04875	1.54936	3.84147	0.2132

Source: Author's computation from EViews 13

* Rejection at the 0.05 level

On the other hand, the maximum eigenvalue test results in Table 5.5. indicate that *At none* the trace statistic values are greater than the critical value (α=0.05). As a result, null hypothesis is rejected, meaning there exist cointegration. Therefore, the Max-eigenvalue test indicates that there is only one cointegration equation at 0.05% level of significance. Therefore, the trace test is preferred as it indicates the existence of a long-run relationship between MP, ED, GFCFM, GDP, and TFP.

5.6 Long run model

Table 5.6 depicts the normalised cointegrating equation which shows the percentage change in mining production to changes in the other variables.

Table 5.6: Normalised cointegrating equation

Normalized cointegrating coefficients (standard error in parentheses				
MP	L_ED	GDP	L_GFCFM	L_TFP
1	-13.3236	-0.23103	-2.322455	32.23573
	(9.9627)	(0.2102)	(1.5489)	(9.9579)
Adjustment coefficients (standard error in parentheses)				
D(MP)	-0.392089			
	(0.140770)			
D(L_ED)	0.007105			
	(0.001170)			
D(GDP)	-0.240615			
	(0.116160)			
D(L_GFCFM)	-0.004322			
	(0.011190)			
D(L_TFP)	0.001095			
	(0.001500)			

Source: Author's compilation from EViews 13

Mining production (MP) was standardised to unity as the endogenous variable in the regression. Using the estimated cointegrated vector, the corresponding coefficients reflect the long-term impact of ED, GDP, GDCFM, and TFP on mining output. The cointegrated vector is expressed as follows:

$$MP + LED + GDP + LGFCFM + LTFP = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.1)$$

Thus:

$$MP - 13.3236\,ED - 0.23103\,GDP - 2.322455\,LN\,GFCFM + 32.23573\,LN\,TFP = 0 \ldots\ldots\ldots (5.2)$$

$$MP = \alpha + 13.3236\,LED + 0.23103\,GDP + 2.322455\,LGFCFM - 32.23573\,LTFP \ldots\ldots\ldots\ldots (5.3)$$

Equation 5.3 highlights a long-term positive relationship between mining production and electricity generation and distribution in South Africa. Specifically, a 1% increase in electricity available for distribution is associated with a 13.32% increase in mining production. This finding aligns with theoretical frameworks and empirical evidence, underscoring the positive correlation between electricity availability and mining output. Additionally, Equation 5.3 indicates a positive impact of gross fixed capital formation on mining production. A 1% increase in investment in mining and TFP results in a 2.32% increase in mining production. This supports the theoretical literature suggesting that capital investment in the mining sector boosts industrial production. The regression results align well with the study's expectations, as detailed in Table 4.1.

However, Equation 5.3 also reveals a negative relationship between TFP and mining production, with a coefficient of -32.24, which was not as expected in Table 4.1. This suggests that a 1% increase in TFP is associated with a 32.24% decrease in mining production, holding other factors constant. While this may seem counterintuitive, it implies that as TFP increases, the industry becomes more efficient, potentially reducing the need for high levels of production. Technological advancements can lead to more efficient extraction and processing methods, which, while increasing TFP, might reduce the necessity for high levels of raw material extraction, thereby lowering overall production volumes. The results of this study are consistent with the findings of previous empirical research presented in Chapter 3. For instance, Inglesi-Lotz and Mabugu (2022) examined the impact of mismatches between electricity supply and demand on economic growth. Their results confirmed a positive relationship between electricity availability, GFCF, and GDP. Similarly, Lenoke (2017) highlighted the significant role of electricity in driving GDP growth in South Africa. Collectively, these studies emphasise the crucial need for a stable and adequate electricity supply to drive economic development.

5.7 Autoregressive distributed lag (ARDL): Bounds testing approach to cointegration

Table 5.7: Bounds cointegration Test

Test Statistic	Value
F-statistic	15.42374

	10%		5%		1%	
Sample	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
30	3.378	4.274	4.048	5.09	5.666	6.988
35	3.29	4.176	3.936	4.918	5.654	6.926
Asymptotic	2.97	3.74	3.38	4.23	4.3	5.23

*I(0) and I(1) are respectively the stationary and non-stationary bounds.

The computed F-statistic is 15.42, exceeding the upper-bound critical values. This indicates that the model's variables are cointegrated, suggesting the presence of a long-run relationship between them.

Table 5.8: Error Correction Model

Variable	Coefficient	Std. Error	T-statistic	Prob.
COINTEQ(-1)	-1.129050	0.191414	-5.898483	0.000000
D(MP(-1))	-0.217509	0.101011	-2.153324	0.041600
D(L_ED)	78.321100	22.821310	3.431928	0.002200
D(L_ED(-1))	79.939900	28.129210	2.841882	0.009000
D(GDP)	0.377502	0.225839	1.671554	0.107600
D(L_GFCFM)	0.782748	2.469666	0.316945	0.754000
D(L_GFCFM(-1))	-6.104385	2.865384	-2.130390	0.043600
R-squared	0.926229	Mean dependent var		-0.203226
Adjusted R-squared	0.907787	S.D dependent var		6.880188
S.E. of regression	2.089281	Akaike info criterion		4.507196
Sum squared resid	104.762300	Schwarz criterion		4.831000
Log likelihood	-63.861540	Hannan-Quinn criter.		4.612748
F-statistic	50.222190	Durban-Watson stat		2.017096
Prob(F-statistic)	0.000000			

Source: Author's computation from EViews 13

According to Widarjono (2009), as cited by Nuzula (2013), the ECM model is considered valid if the Error Correction Coefficient (ECT) term is negative and statistically significant. The range of the ECT coefficient should be between 0 and -1; this ensures that the system will be convergent. As shown in Table 5.8, Cointeq (-1) represents the error correction term (ECT). This term captures the speed at which the dependent variable returns to equilibrium after a change in the independent variables. The value of ECT is -1.129, with a probability of 0.0000, significant at 5%, which indicates over-correction/ oscillatory convergence. Although theoretically, the ECT should be between 0 and -1, several scholars and researchers have been observing ECT that is above -1, indicating that variables tend to revert to their long run equilibrium relationship quickly. Silva *et al.* (2020) tested the impact of loadshedding on industrial performance, and the ECT results were -2.11. Phiri and Moyo (2021) evaluated the impact of loadshedding on manufacturing production in South Africa, and their ECT results were -1.82.

While the equilibrium value of -1.129 can be interpreted as indicating an imbalance of mining production due to loadshedding for years 1990-2022 is over corrective, in the case of disequilibrium the model will be able to run back into equilibrium in the next year at a rate of 112.9%. The value of ECT is significant at the level of (α=5%), and it can be concluded that there is a relationship between ECM and the cointegration test.

Overall, the regression for the underlying ARDL model demonstrates a good fit, with an R-squared of 0.92% and an adjusted R-squared of 0.90%. This suggests that the model explains most of the variation in the dependent variable, indicating a strong relationship between the explanatory variables and the dependent variable.

5.8 Diagnostic test

The diagnostic test in Table 5.9 shows that the residuals follow a normal distribution. Additionally, the results from the Breusch-Godfrey test confirm the absence of serial correlation. The Ramsey's RESET test is for misspecification. The ARCH and Breusch Pegan-Godfrey tests indicate that there is no heteroskedasticity.

Table 5.9: Diagnostic tests results

Test	Null hypothesis (H0)	P value	Conclusion
Jarque-Bera	Residuals are normally distributed	0.8682	Do not reject H0 since PV>0.05 L.O.S
Breusch-Godfrey	No serial correlation	0.1647	Do not reject H0 since PV>0.05 L.O.S
Breusch-Pegan Godfrey	No Heteroskedasticity	0.9993	Do not reject H0 since PV>0.05 L.O.S
Ramsey RESET	The model is correctly specified	0.0902	Do not reject H0 since PV> 0.05 L.O.S
ARCH	No Heteroskedasticity	0.1919	Do not reject H0 since PV>0.05 L.O.S

Source: Author's computation from EViews13

5.8.1 Variance inflation factor

The principal aim of VIF is to measure the extent to which the variance of a regression coefficient is augmented because of multicollinearity. Elevated VIF values signify a strong correlation among predictor variables, potentially resulting in incorrect and unstable estimates of regression coefficients.

The Null Hypothesis posits that no multicollinearity exists among the independent variables. This indicates that the variance of the computed regression coefficient remains unaffected by the correlation among the predictor variables. The alternative hypothesis posits the existence of multicollinearity among the independent variables. This indicates that the variance of the predicted regression coefficient is exacerbated by the correlation among the predictor variables.

Table 5.10: Variance inflation factor

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
L_ED	43.58973264	37966.77214	8.567097642
L_GFCFM	1.087811889	1077.33045	9.653980703
L_TFP	85.34755448	4.717109169	1.888456186
GDP	0.054323857	5.189805045	1.245676977
C	2896.72479	26528.49763	

Source: Author's computation from EViews13

Table 5.10 illustrates L_ED (VIF = 8.57), a value approaching 10, signifying a substantial degree of multicollinearity. This indicates that L_ED exhibits a strong correlation with other predictor variables in the model. L_GFCFM (VIF = 9.65) approaches 10, signifying a substantial degree of multicollinearity. L_GFCFM exhibits a strong correlation with other predictor variables. L_TFP (VIF = 1.89) indicates low multicollinearity, as this value is below 5. L_TFP exhibits a non-problematic degree of correlation with other predictor variables. The GDP value (VIF = 1.25) is far below 5, signifying minimal multicollinearity. The correlation between GDP and other predictor factors is minimal.

5.9 Stability test results

Figure 5.6 CUMSUM and CUMSUM of squares stability test
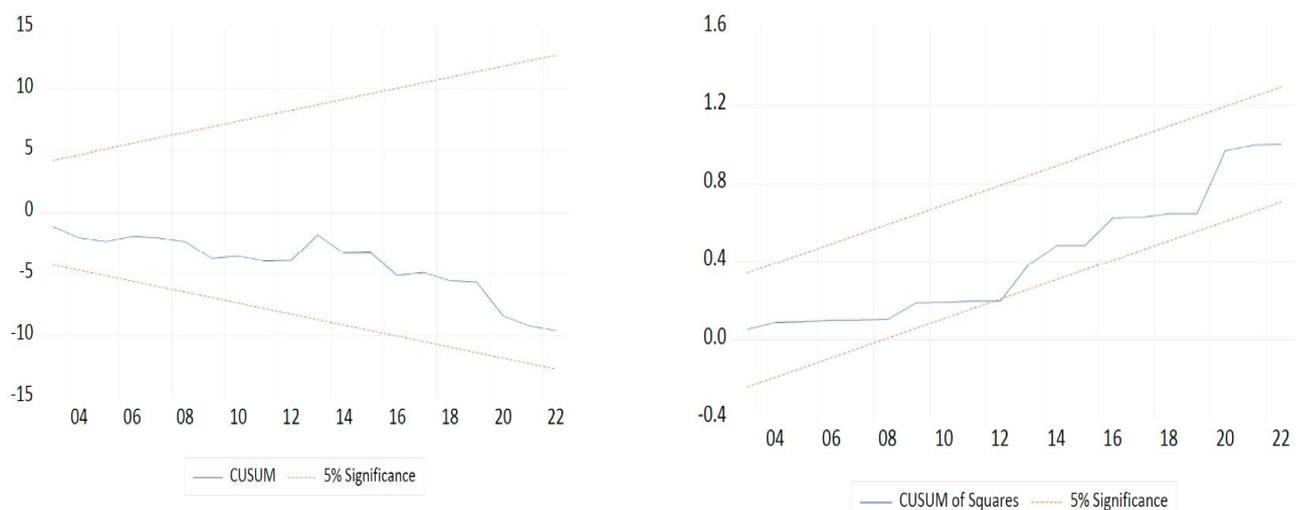
Source: Author's compilation from EViews13

The CUSUM and CUSUMSQ tests in Figure 5.6 demonstrate that the model remains relatively stable, as the cumulative totals stay within the critical boundaries. The variation between the significance lines at the 5% level indicates that the model is stable.

5.10 The impulse response function and variance decomposition analysis

5.10.1 The impulse response function

Figure 5.7: The impulse response function results
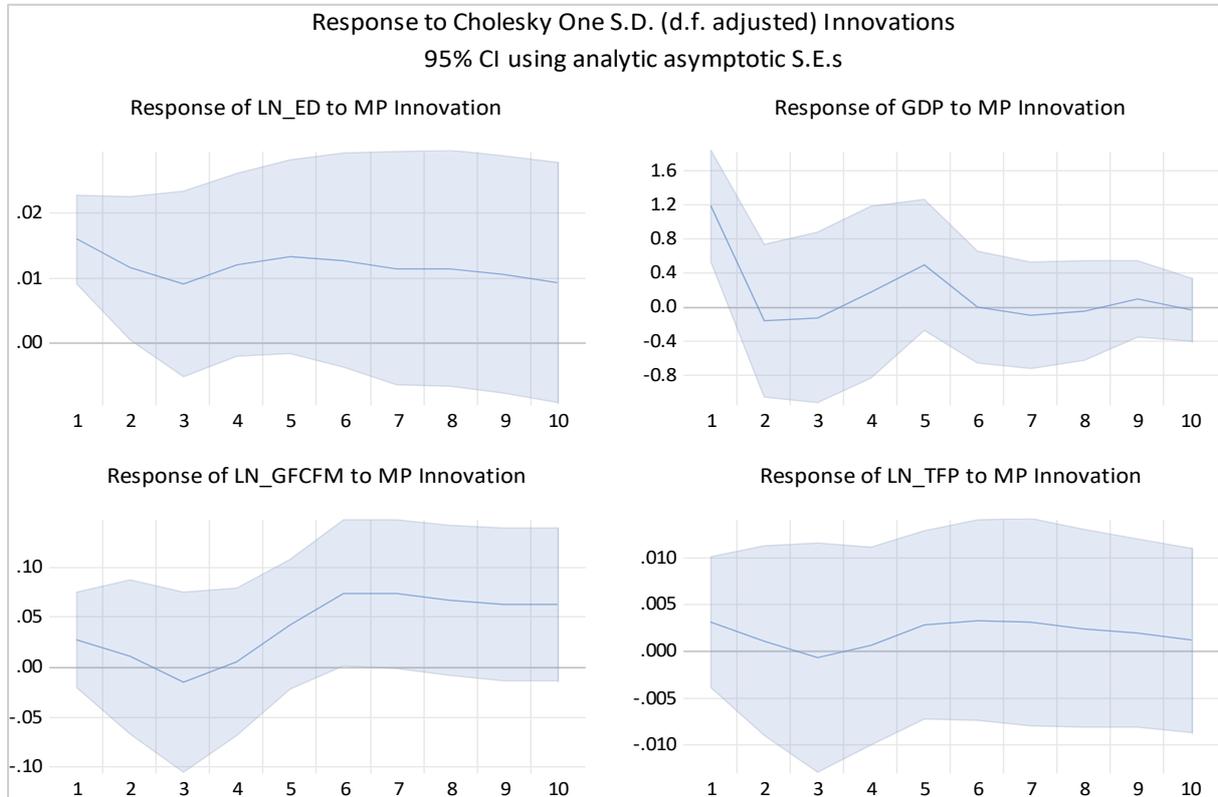
Source: Author's computation from EViews13

The impulse response function illustrates how the current and future values of each variable react to a one-unit shock in the current value of one of the VAR errors. It reveals the impact of an external shock on the entire process over time. A rapid increase in electricity generation and distribution, with gross fixed capital formation during the rise in mining production, aligns with the economic hypothesis that electricity is positively correlated with mining output. A further surge in consumption occurs during the third quarter, perhaps as a delayed reaction to the rise in investment.

5.10.2 Variance decomposition analysis

Table 5.11: Variance decomposition analysis of mining production

Variance Decomposition of MP:						
Period	S.E.	MP	L_ED	GDP	L_GFCFM	L_TFP
1	3.131853	100.0000	0.0000	0.0000	0.0000	0.0000
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
2	4.538499	58.2458	0.4989	15.3487	11.3828	14.5238
		(11.9517)	(4.2057)	(11.6960)	(9.1901)	(8.9813)
3	4.815967	54.1576	0.7126	13.6386	12.2377	19.2535
		(12.7484)	(5.2533)	(10.7151)	(9.4961)	(10.3187)
4	4.956141	52.1589	1.3272	15.5882	11.5594	19.3664
		(13.4625)	(5.6540)	(10.8027)	(9.1313)	(10.3187)
5	5.035228	51.7278	1.4638	16.2961	11.7479	18.7644
		(13.0686)	(5.7828)	(10.4556)	(8.9319)	(10.4953)
6	5.149788	51.9234	1.4144	16.3474	11.6822	18.6327
		(13.8832)	(5.9912)	(10.5859)	(8.7651)	(10.8025)
7	5.200973	51.1070	1.5425	16.1040	11.7092	19.5374
		(13.9092)	(6.7025)	(10.8735)	(9.0587)	(11.2813)
8	5.207082	51.0489	1.6014	16.1205	11.6971	19.5322
		(14.3730)	(7.1377)	(10.9653)	(9.2610)	(11.2813)
9	5.219556	51.1229	1.6158	16.1374	11.6940	19.4441
		(14.0423)	(7.4977)	(11.0984)	(9.3574)	(11.0952)
10	5.232275	51.1083	1.5939	16.1176	11.6917	19.4885
		(14.5643)	(7.6773)	(11.1336)	(9.3862)	(11.5098)

Source: Author's computation from EViews13

Table 5.11 above depicts the variance decomposition of MP over 10 periods, and it reveals how the influence of various economic factors changes over time. Initially, MP explains 100% of its variance, indicating that short-term fluctuations are primarily driven by factors within the mining sector itself. However, as time progresses, the impact of other variables such as GDP, Total Factor Productivity (L_TFP), and Electricity generated and distributed (L_ED) becomes more pronounced. By the 10th period, MP's contribution to its variance decreases to about 60.2%, with GDP and L_TFP emerging as significant contributors. This shift highlights the increasing interrelation of mining production with broader economic conditions, suggesting that while mining-specific factors are crucial in the short term, the overall economic environment plays a larger role in the long term. These findings align with existing empirical literature such as study by Inglesi-Lotz (2011) which have shown that electricity supply constraints and broader economic indicators have a cumulative long-

term effect on industrial and sectoral performance in South Africa. As the mining sector is energy-intensive and deeply embedded in the national economy, it becomes more sensitive over time to macroeconomic trends and productivity shifts.

5.11 Conclusion

This chapter presents a thorough analysis of the effects of loadshedding on South Africa's mining sector, employing the ARDL bounds test approach and multiple econometric models. The findings suggest a substantial long-term correlation between MP and essential economic factors, including ED, GDP, GFCFM, and TFP. A long-term relationship between mining production and the independent variables has been confirmed by the ARDL bounds test and Johansen cointegration test, implying that lasting effects on mining output are caused by changes in electricity availability, GDP, and capital investment. The significant impact of a reliable energy supply on enhancing mining production is underscored by the positive coefficient for electricity availability in the cointegrated vector, consistent with economic theories that stress the importance of infrastructure in industrial productivity. The importance of investing in mining infrastructure and technology is shown by the favourable effect of GFCFM, reinforcing the notion that industrial capacity and efficiency are improved through capital investment. The negative coefficient for TFP indicates that enhanced mining efficiency may result from technological developments, diminishing the necessity for elevated output volumes, which aligns with the economic notion that greater efficiency can reduce production costs and resource consumption.

The Error Correction Model (ECM) empirically indicates a gradual adjustment process to equilibrium, with an adjustment speed of 112.9%, implying that the mining sector needs time to recuperate from interruptions induced by loadshedding. The impulse response function and variance decomposition analysis indicate that, whereas short-term variations are primarily driven by mining-specific factors, larger economic situations gain significance with time. These findings corroborate ideas that underscore the significance of infrastructure, including electrical supply, in augmenting industrial productivity, economic growth, and the necessity of investment in physical capital for economic development. The inverse correlation between TFP and mining output also illustrates the hypothesis that technical developments can enhance production efficiency, hence diminishing the necessity for elevated output levels. The

investigation has proven a substantial influence on the mining sector in South Africa. A reliable electrical supply, capital investment, and technological innovations are essential for maintaining and improving mining output. These findings provide important insights for policymakers and industry stakeholders aiming to mitigate the adverse effects of loadshedding and promote sustainable growth within the mining sector.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Summary and conclusion

This study has thoroughly analysed the impact of supply shocks on the mining sector in South Africa from 1990 to 2022. Using the ARDL bounds method and the Johansen cointegration test, the research demonstrated a significant long-term relationship between mining production and key economic variables such as electricity availability, GDP, GFCFM, and TFP.

Chapter one introduced the critical role of electricity in driving economic growth, particularly in energy-intensive sectors like mining. It traced the history of electricity shortages in South Africa, which began in 2007, and explored the subsequent impacts on the economy. The chapter also defined the problem statement, research questions, objectives, hypothesis, significance, and delimitations, with the primary aim being to assess the effect of supply shocks on the mining sector.

Chapter two provided a detailed overview of South Africa's energy sector, including the history and causes of loadshedding. It reviewed government measures aimed at transitioning to green energy and the challenges faced. The chapter further examined the impact of loadshedding on mining production, government revenue, employment, and export income, emphasising the interdependent nature of the energy and mining sectors and the severe effects of energy shortages on mining operations.

Chapter three, literature review, explored theoretical frameworks and empirical studies related to shortage in energy supply and its impact on the mining sector. The review covered classical economics, neoclassical theory, the Solow growth model, and infrastructure investment theory, underscoring the critical role of a stable electricity supply in economic development. Empirical research from South Africa and other countries confirmed the conclusions of the study. Lenoke (2017) examined the effects of power outages, electricity usage, and electricity tariffs on South Africa's economy, emphasizing the essential importance of a reliable electricity supply. Inglesi-Lotz and Ajmi (2021) examined the impact of increasing electricity prices and inconsistent supply on FDI in South Africa, demonstrating that energy volatility can dissuade

international investors. These studies jointly highlighted the critical need for a reliable and adequate energy supply to promote economic stability and prosperity in South Africa. The study indicated a negative correlation between TFP and mining output, implying that technical innovations may enhance mining efficiency, diminishing the necessity for elevated production levels. This illustrated the economic idea that enhanced efficiency can reduce production costs and resource consumption, as articulated by Gordon (2011) and corroborated by the Solow Model, which highlights the significance of technical advancement in sustained economic growth. The study also drew on empirical research from other African countries, such as Zimbabwe and Zambia, which have faced similar challenges with electricity loadshedding. For example, Kasek and Hosking (2012) assessed the impact of loadshedding on the mining sector in Zimbabwe, revealing that power outages significantly reduce mining output and revenue. Similarly, Mulenga et al. (2016) conducted an econometric analysis of productivity within Zambia's manufacturing sector, revealing that power disruptions adversely affect business productivity, especially for those without alternative sources of electricity.

Chapter 4, methodology, detailed the research design, data sources, sampling methods, and analytical models. The study employed the Auto-Regressive Distributed Lag (ARDL) model to analyse both short and long-term effects, while various diagnostic tests ensured the robustness and reliability of the results.

Chapter Five presented the study's findings, which included descriptive statistics, unit root tests, lag length selection criteria, cointegration tests, and the error correction model. The results revealed a significant long-term relationship between mining production and key economic variables, including electricity availability, GDP, and total factor productivity. The findings reinforced the importance of a stable electricity supply, infrastructure investment, and technological innovations for sustaining mining productivity. The ECM demonstrated a slow transition process towards equilibrium, with an adjustment speed of 112.9%, highlighting the mining sector's resilience to disruptions. The impulse response function and variance decomposition analysis indicated that, whereas short-term variations are primarily driven by mining-specific factors, larger economic situations gain significance over time. This corresponded with the conclusions of Amusa, Amusa, and Mabugu (2009), who emphasized the

detrimental effects of energy shortages on economic activities and foreign direct investment.

The findings emphasised the vital significance of a steady and dependable energy supply in maintaining and improving mining operations. The affirmative coefficient for power availability in the cointegrated vector corresponded with economic theories that underscore the significance of infrastructure in industrial production. This aligns with the theoretical framework proposed by McDonald (2009), who asserts that electricity is a catalyst for economic growth, and shortages can severely impede this expansion. The positive effect of GFCFM highlighted the significance of investing in mining infrastructure and technology, emphasizing that industrial capacity and efficiency are enhanced through capital investment.

The study concluded that shortage in electricity supply significantly affects the mining sector in South Africa. To alleviate these adverse effects and foster sustainable growth, it is essential to secure a reliable electrical supply, invest in infrastructure, and adopt technological innovations. These findings offer significant insights for policymakers and industry stakeholders aiming to improve the resilience and productivity of the mining sector. Mitigating the issues of loadshedding necessitates a comprehensive strategy, encompassing investment in infrastructure modernization, enhancement of energy generation capacity, and diversification of energy sources.

6.2. Policy recommendations

The estimated model suggests that a 1% increase in electricity availability for distribution results in a 13.32% increase in mining output. These findings emphasise the critical importance of a sustainable electricity supply for overall economic growth, particularly for energy-intensive sectors such as mining. To mitigate the persistent decline in energy supply and the resultant electricity loadshedding, the following recommendations are proposed:

- Drawing from the theoretical literature discussed in chapter three, particularly the insights of Solow (1956), investment in R&D is essential for driving innovation and technological progress in the energy sector. Prioritizing R&D

can help South Africa develop advanced and efficient energy technologies, thereby alleviating the impact of load-shedding on the mining industry. By fostering collaborations with academic institutions and industry stakeholders, South Africa can not only address the immediate challenges of loadshedding but also establish a more resilient and sustainable energy infrastructure that promotes long-term economic growth.

- One of the primary causes of electricity loadshedding, as identified in chapter two, is the aging infrastructure of Eskom, South Africa's largest electricity provider. To mitigate power outages and ensure a reliable electricity supply, substantial investment is required in modernizing power plants, upgrading transmission infrastructure, and expanding generation capacity, particularly through renewable energy sources such as solar and wind. Additionally, enhancing energy efficiency and demand side management through initiatives such as mandatory energy audits and demand response programs can optimise electricity use and help alleviate grid overloads.

- Despite the addition of 4,800 MW from the Medupi and Kusile power plants, the national grid continues to fall short in meeting growing energy demands. This underscores the urgent need for accelerated investment and development of renewable energy initiatives nationwide. As of 2024, South Africa has approximately 5 GW of installed renewable energy capacity through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), with numerous wind and solar projects either operational or in progress (Department of Mineral Resources and Energy, 2023). Several national programs are already in place to reduce reliance on coal and integrate renewable energy sources:

  o Renewable Energy Independent Power Producer Procurement Programme (REIPPPP): This program has been instrumental in attracting private investment and advancing renewable energy projects across the country.

  o The Just Energy Transition Partnership (JETP): An international initiative designed to facilitate South Africa's transition from a coal-dependent

energy system to cleaner, renewable sources such as wind, solar, and hydrogen, while ensuring social fairness.

- o The Integrated Resource Plan (IRP): South Africa's power planning framework, the IRP, outlines strategies for achieving a sustainable energy mix. It sets clear objectives for the transition to renewable energy sources, including wind and solar, while reducing dependence on coal. The IRP aims to balance energy security, cost-effectiveness, and environmental sustainability through diversification, increasing renewable capacity, and modernizing the grid (Montmasson-Clair and Ryan, 2014).

- Despite the progress made through these programs, challenges remain in their implementation. Policy uncertainty, governance issues, regulatory constraints, and financial limitations have hindered the efficient execution of these initiatives (News24, 2024). Insufficient cooperation among stakeholders and slow investment in renewable technologies further impede progress. To maximize the potential benefits of these programs, it is crucial to resolve these challenges.

- Effective management, implementation and collaboration among government, Eskom, and private sector stakeholders are essential to overcoming these barriers and accelerating the transition to green energy. This would not only alleviate the effects of loadshedding but also support the broader goals of economic growth, environmental sustainability, and energy security.

6.3 Limitations of the study

The study presents several limitations and recommendations for future research. Data constraints include reliance on historical information from 1990 to 2022, which may not accurately represent the current condition of the mining industry and the effects of loadshedding. While using electricity produced or available for distribution as proxy for shortage in energy supply, provides valuable insights, it is acknowledged that these measures may not capture all aspects of loadshedding. The focus on mining restricts the applicability of findings to other sectors, such as agriculture, due to limited literature

in that area. The geographical scope is confined to South Africa, and the effects of loadshedding may differ in other countries. The ARDL bounds and the Johansen cointegration test used in the study assume linear relationships, which may not capture complex dynamics.

6.4 Suggestions for further research

It is recommended to integrate contemporary data and broaden the analysis to include more industries, such as manufacturing, agriculture, and services. Comparative analysis with countries facing similar energy challenges may reveal optimal approaches. Employing non-linear models could uncover more intricate links between electricity supply and industrial performance.

7. LIST OF REFERENCES

Akinbami, O. M., Oke, S. R., & Bodunrin, M. O. (2021). The state of renewable energy development in South Africa: An overview. *Alexandria Engineering Journal, 60*(6), 5077-5093.

Alabi, A. O. (2021). The impact of power outages on Nigeria's economic growth: A time series analysis. *Journal of African Development*, 23(2), 35-47. Retrieved from https://doi.org/10.1186/s42200-021-00025-w

Alabi, T. (2021). The correlation between power outages and GDP in Nigeria: An econometric time-series analysis. *Economic Modelling*, 54, 89-102.

Ali, S., & Raza, H. (2020). Loadshedding and its economic consequences: Evidence from Pakistan. *Journal of Economic Policy Reform*, 23(4), 307-319. Retrieved from https://doi.org/10.1080/17487870.2020.1835523

Antin, D. (2013). The South African mining sector: An industry at a crossroads. *Economy Report South Africa*, 1-22.

Arrow, K. J., & Kurz, M. (1970). *Public investment, the rate of return, and optimal fiscal policy*. Johns Hopkins University Press.

Aschauer, D. A. (1989). Is public expenditure productive? *Journal of Monetary Economics, 23*(2), 177-200. Retrieved from https://doi.org/10.1016/0304-3932(89)90047-8

Asteriou, D., & Hall, S. G. (2021). *Applied econometrics*. Bloomsbury Publishing.

Auctus Metals. (2020). *Major impact of South Africa's energy crisis on future supply of platinum group metals*. Retrieved from https://auctusmetals.com/major-impact-of-south-africas-energy-crisis-on-future-supply-of-platinum-group-metals/

Davis, D. (2021). The impact of South Africa's energy crisis on PGM mine supply. Auctus Metals Portfolio. Retrieved from https://auctusmetals.com/major-impact-of-south-africas-energy-crisis-on-future-supply-of-platinum-group-metals/

105943

Boston Consulting Group. (2024). South Africa: Key challenges for miners. Retrieved from https://www.bcg.com/publications/2024/south-africa-key-challenges-for-miners

Boyse, F., Causevic, A., Duwe, E., & Orthofer, M. (2014). *Sunshine for mines: Implementing renewable energy for off-grid operations*. Washington, DC: Carbon War Room.

Budget Review. (2023). *Revenue trends and tax proposals*. National Treasury.

Cameron, G. (2010). Classical economics and economic growth. In *Economic growth* (pp. 9-15). London: Palgrave Macmillan UK.

Clark, J. B. (1899). *The distribution of wealth: A theory of wages, interest, and profits*. New York: Macmillan.

Cobb, C. W., & Douglas, P. H. (1928). A theory of production. *The American Economic Review, 18*(1), 139-165. Retrieved from https://www.jstor.org/stable/1801217

Creamer, M. (2021). Investment in mining crucial to ensure continued contribution to economy-PwC. *Mining Weekly.* Retrieved from https://www.miningweekly.com/article/investment-in-mining-crucial-to-ensure-continued-contribution-to-economy-pwc-2021-10-05

DasNair, R., Fatman, D., Chinembiri, E., Montmasson-Clair, G., Ryan, G., & Nyakabawo, W. (2015). *The impact of electricity price increases on the competitiveness of selected mining sector and smelting value chains in South Africa.* Trade and Industrial Policy Strategies (TIPS) and Global Green Growth Institute (GGGI).

Department of Mineral Resources and Energy. (2021). *South African Energy Sector Report 2021.* Retrieved from https://www.dmre.gov.za/Portals/0/Energy_Website/files/media/explained/2021-South-African-Energy-Sector-Report.pdf.

Department of Mineral Resources and Energy. (2022). *South African Energy Sector Report 2022.* Retrieved

from https://www.dmre.gov.za/Portals/0/Energy_Website/files/media/explained/2022-South-African-Energy-Sector-Report.pdf

Department of Mineral Resources and Energy. (2023). Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). Retrieved from https://www.energy.gov.za

Douglas, C., & Dube, A. (2002). The economic impact of power supply interruptions: A review. *Journal of Energy Economics*, 15(3), 214-230.

Erero, J. (2023). Impact of loadshedding in South Africa: A CGE analysis. *Journal of Economics and Political Economy, 10*(2), 78-94.

Eskom. (2019). *Annual report 2019.* Eskom. Retrieved from https://www.eskom.co.za/annual-report-2019

Eskom. (2022). Eskom Annual Report 2022. Retrieved from https://www.eskom.co.za/wp-content/uploads/2021/08/CO-0007-Coal-in-SA-Rev-16.pdf

Eskom. (2023a). *Annual report on energy production and loadshedding trends in South Africa.* Retrieved from https://www.eskom.co.za/eskom-releases-its-results-for-the-2022-23-financial-year/

Eskom. (2023b). *Weekly System Status Report.* South Africa: Pretoria.

Fried, S., & Lagakos, D. (2020). Electricity and firm productivity: A general-equilibrium approach (No. w27081). *National Bureau of Economic Research.*

Goldberg, A. (2015). The economic impact of loadshedding: The case of South African retailers (Doctoral dissertation, University of Pretoria).

Griffin, J. R., & Steel, R. R. (2000). *Electric power: A strategic resource.* MIT Press.

Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics* (5th ed.). McGraw-Hill Irwin.

History Hit. (n.d.). Adam Smith's Wealth of Nations: 4 key economic theories. Retrieved from https://www.historyhit.com/adam-smiths-wealth-of-nations-4-key-economic-theories/

iHarare. (2023). Zimbabwe plunged back into darkness: ZESA explains increased loadshedding. Retrieved from iHarare.

IndexBox. (2023, October 10). South Africa's coal exports in 2023: Key trends and insights. IndexBox. Retrieved from https://www.indexbox.io/blog/south-africa-coal-exports-2023/

Integrated Annual Review. (2023). Minerals Council South Africa. Retrieved from https://www.mineralscouncil.org.za

International Energy Agency. (2023). South Africa Energy Profile. Retrieved from https://www.iea.org

IOL. (2023). Loadshedding: Zimbabwe electricity provider warns of increased power cuts. Retrieved from Retrieved from https://www.iol.co.za/news/africa/loadshedding-zimbabwe-electricity-provider-warns-of-increased-power-cuts-till-tomorrow-d117bce2-3408-49d8-86a7-94f6fb663110.

Jamal, M. A., & Nazir, M. (2019). The impact of power loadshedding on Pakistan's GDP: A sectoral analysis. *Pakistan Development Review*, 58(2), 149-162.

Just Energy Transition Partnership. (2023). South Africa's Just Energy Transition. Retrieved from https://www.jetp.org

Khan, M. Z., & Akhtar, R. (2020). The effect of loadshedding on economic growth in Pakistan. *Energy Economics*, 91, 104871. Retrieved from https://doi.org/10.1016/j.eneco.2020.104871

Kripfganz, S., & Schneider, D. C. (2018). ARDL: Estimating autoregressive distributed lag and equilibrium correction models. In *Proceedings of the 2018 London Stata conference* (Vol. 9).

Kuhudzai, R. J. (2023). *Zimbabwe declares that load-shedding has ended — However, there is still a lot of work to do*. CleanTechnica. Retrieved from https://cleantechnica.com/2023/08/21/zimbabwe-declares-that-load-shedding-has-ended-however-there-is-still-a-lot-of-work-to-do/

Kuteya. (2016). The impact of power rationing on Zambia's agricultural sector. Retrieved from Academia.

Lanne, M., & Nyberg, H. (2016). Generalised forecast error variance decomposition for linear and nonlinear multivariate models. *Oxford Bulletin of Economics and Statistics, 78*(4), 595-603. Retrieved from https://doi.org/10.1111/obes.12125

Lenoke, M. (2017). *The impact of loadshedding on the economic growth of South Africa* (Master's dissertation). North-West University. Retrieved from https://repository.nwu.ac.za/handle/10394/35217.

Loewald, C. (2023). Occasional bulletin of economic notes. *OBEN/23/01*. South African Reserve Bank.

Mankiw (2021): References a more modern source discussing marginal cost, market equilibrium, and the implications of disruptions like loadshedding.

Mankiw, N. G. (2021). *Principles of economics* (9th ed.). Cengage Learning.

Marshall, A. (1890). Principles of Economics. This work discusses general neoclassical concepts, including marginal productivity and resource allocation.

Meridian Economics. (2024, March 18). *Review of the IRP 2023: Comments for submission to the Director-General of the Department of Mineral Resources and Energy*.

Mill, J. S. (1848). Principles of Political Economy. John W. Parker.

Miller, E. (2008). An assessment of CES and Cobb-Douglas production functions (pp. 2008-2005). Washington, DC: Congressional Budget Office.

Minerals Council South Africa. (2022). *Facts & Figures Pocketbook 2022*. Retrieved from https://www.miningreview.com/base-metals/the-minerals-council-publishes-facts-figures-pocketbook-2022/

Minerals Council South Africa. (2023). Integrated Annual Review 2023: Our Context. Retrieved from https://www.mineralscouncil.org.za/reports/2023/downloads/mcsa-iar2023-our-context.pdf

Minerals Council South Africa. (2023). Integrated Annual Review 2023. Retrieved from https://www.mineralscouncil.org.za

Minerals Council South Africa. (2024). Home - Minerals Council South Africa. Retrieved from https://www.mineralscouncil.org.za/

Mining Indaba. (2023). *Updated loadshedding code includes up to 16 stages to reduce grid collapse risk*. Retrieved from https://www.miningweekly.com/article/updated-loadshedding-code-includes-up-to-16-stages-to-reduce-grid-collapse-risk-2023-07-04

Mining Taxation. (2013). *Economic Tax Analysis*. Retrieved from https://static.pmg.org.za/131106mining.pdf.

Mongale, I. P., Mukuddem-Petersen, J., Petersen, M. A., & Meniago, C. (2013). Household savings in South Africa: An econometric analysis. *Mediterranean Journal of Social Sciences, 4*(13), 519.

Montmasson-Clair, G., & Ryan, G. (2014). *Repositioning electricity planning at the core: An evaluation of South Africa's Integrated Resource Plan*. Trade & Industrial Policy Strategies (TIPS) for the National Economic Development and Labour Council (Nedlac).

Muganasinghe, L. (1979). *Economics of power system reliability and planning*. *Energy, 4*(4), 405–421. Retrieved from https://doi.org/10.1016/0360-5442(79)90031-4

Muganasinghe, L. (1979). *Economics of power system reliability and planning*. *Energy, 4*(4), 405-421. Retrieved from https://doi.org/10.1016/0360-5442(79)90031-4

Mukupa, Phiri, & Kunda. (2018). The impact of loadshedding on the cost of living: A Zambian perspective. Retrieved from ZCAS Repository.

Munasinghe, M. (1979). *The economics of power system reliability and planning: Theory and case study*. Baltimore: Johns Hopkins University Press.

Munasinghe, M., & Gellerson, M. (1979). Economic criteria for optimising power system reliability levels. *The Bell Journal of Economics*, 353-365.

Mutambo, H., Kawimbe, S., Meki-Kombe, C., & Mwange, A. (2023). Understanding the impact of electricity loadshedding on small and medium enterprises: Exploring

theoretical underpinnings. *European Journal of Business and Management, 15*(15), 80-105. Retrieved from https://doi.org/10.7176/EJBM/15-15-08

National Planning Commission. (2012). *National Development Plan 2030: Our future - make it work*. The Presidency, Republic of South Africa.

Nduhuura, P., Garschagen, M., & Zerga, A. (2020). Mapping and spatial analysis of electricity loadshedding experiences: A case study of communities in Accra, Ghana. *Energies, 13*(17), 4280. Retrieved from https://doi.org/10.3390/en13174280

Nduhuura, P., Garschagen, M., & Zerga, A. (2020). Mapping and spatial analysis of electricity loadshedding experiences: A case study of communities in Accra, Ghana. *Energies, 13*(17), 4280. Retrieved from https://doi.org/10.3390/en13174280

News24. (2021, September 13). *Zimbabwe announces 12-hour loadshedding*. Retrieved from https://www.news24.com/Fin24/zimbabwe-announces-12-hour-load-shedding-20210913.

News24. (2023, May 20). *Mining sector reduces electricity demand by 15%, leading to a 3.7% drop in production*. Retrieved from https://www.news24.com/fin24/economy/analysis-the-real-cost-of-load-shedding-and-how-the-power-crisis-can-be-solved-20230520

News24. (2024, October 28). *JETP billions: Rich nations raise concerns over SA's slow progress in greening energy*. Retrieved from https://www.news24.com/fin24/climate_future/jetp-billions-rich-nations-raise-concerns-over-sas-slow-progress-in-greening-energy-20241028

Nielsen, H. B. (2005). Non-stationary time series and unit root tests. *Unpublished Lecture Notes for Econometrics, 2*.

Nwokoye, E. S. (2017). Power infrastructure and electricity in Nigeria: Policy considerations for economic welfare. *KIU Journal of Humanities, 2*(1), 5-17. Retrieved from https://www.researchgate.net/publication/326919034PowerinfrastructureandelectricityinNigeriaPolicyconsiderationsforeconomicwelfare-KIUJournalofHumanities

Ogbe, M. (2014). Living under the electricity loadshedding in Ghana: A case study of businesses in Accra Newtown and residences in North Legon suburbs of Accra, Ghana. *NTNU Open*. Retrieved from https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2448247

Phiri, A., & Moyo, S. (2021). The impact of loadshedding on manufacturing production in South Africa. *Journal of Energy in Southern Africa*, 32(1), 1-12. Retrieved from https://doi.org/10.17159/2413-3051/2021/v32i1a7389

Phiri. (2014). Electricity loadshedding: An econometric analysis of the productivity of firms in the manufacturing sector in Lusaka. Retrieved from Academia.

Pierce, W., & Le Roux, M. (2022). *Statistics of utility-scale power generation in South Africa: H1-2022 (1 Jan 2022 – 30 June 2022)*. CSIR Energy Centre.

Presidential Climate Finance Task Team. (2022). *South Africa's Just Energy Transition Investment Plan (2023-2027): Building a pathway towards a low carbon and climate resilient society*. Briefing to Portfolio Committee on Mineral Resources and Energy.

Rejuvenating South Africa's Economy. (2022). *Inclusive Society Institute*. Retrieved from https://www.inclusivesociety.org.za

Research Method. (n.d.). Correlational research. *Research Method*. Retrieved from https://researchmethod.net/correlational-research/#google_vignette.

Ricardo, D. (1817). On the Principles of Political Economy and Taxation. John Murray.

Sadiq, M., & Rehman, M. (2018). The impact of loadshedding on the industrial sector of Pakistan. *International Journal of Economics, Commerce and Management, United Kingdom*, 6(12), 16-26.

SARB. (2023). *Quarterly bulletin*. (2022). Retrieved from Retrieved from https://www.resbank.co.za/en/home/publications/publication-detail-pages/quarterly-bulletins/quarterly-bulletin-publications/2022/full-quarterly-bulletin—no-306—december-202.

Shahbaz, M., & Ahmed, N. (2021). Energy crisis and its implications on manufacturing sector growth in Pakistan: An empirical analysis. *Environmental*

Economics and Policy Studies, 23(3), 431-448. Retrieved from https://doi.org/10.1007/s10018-021-00314-0

Shibata, R. (1980). A Further Results on Asymptotic Optimality of AIC. *Biometrika, 67*(2), 497-502. Retrieved from https://doi.org/10.1093/biomet/67.2.497

Sileyew, K. J. (2019). Research design and methodology. *Cyberspace*, 1-12.

Silva, A., Smith, B., Johnson, C., Lee, D., and Patel, E. (2020). The impact of loadshedding on industrial performance. Energy Economics, 72, 259-274. Retrieved from https://doi.org/10.1016/j.eneco.2020.01.009.

Smith, A. (1776). *The wealth of nations*. W. Strahan and T. Cadell.

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. The Quarterly Journal of Economics, 70(1), 65-94. Retrieved from https://www.jstor.org/stable/23606794

Solow, R. M. (1987). Growth theory and after. Nobel Prize Lecture. Retrieved from https://www.nobelprize.org/prizes/economic-sciences/1987/solow/lecture/

South African Revenue Service. (2023). *Annual Report 2022/23*. Pretoria: South African Revenue Service.

Statistics South Africa. (2017). *Mining: A brief history*. Retrieved from https://www.statssa.gov.za/?p=9720

Statistics South Africa. (2023). *Quarterly Labour Force Survey: Quarter 1, 2023* (Statistical release P0211). Statistics South Africa. Retrieved from https://www.statssa.gov.za/publications/P0211/P0211QuarterlyLabourForceSurveyQ1_2023.pdf

Timilsina, G. R., Sapkota, P., & Steinbuks, J. (2018). How much has Nepal lost in the last decade due to loadshedding? An economic assessment using a CGE model. *World Bank Policy Research Working Paper, (8468)*.

Udo, E. J., Akpan, U. F., & Etim, E. E. (2018). Welfare implications of power outages on Nigerian households. *Energy Policy*, 112, 456-465.

Udo, R. K., Sani, M., & Ajayi, O. O. (2018). Power outages and household welfare in Nigeria. Energy for Sustainable Development, 45, 139-149. Retrieved from https://doi.org/10.1016/j.esd.2018.01.005

Walsh, K., Theron, R., & Rees, C. (2021). *Estimating the economic cost of loadshedding in South Africa*. Nova Economics. Retrieved from https://www.nersa.org.za/wp-content/uploads/2021/09/Appendix-C_Estimating-the-Economic-Cost-of-Load-Shedding-in-South-Africa-Report.pdf

Wood Mackenzie. (2015). *Can Glencore and Eskom secure optimal future?* Wood Mackenzie. Retrieved from https://www.woodmac.com/reports/coal-can-glencore-and-eskom-secure-optimums-future-31802224/

Yang, H. Y. (2000). A note on the causal relationship between energy and GDP in Taiwan. *Energy economics*, *22*(3), 309-317.

Yu, Z., Ridwan, I. L., Tanveer, M., & Khan, S. A. R. (2023). Investigating the nexuses between transportation infrastructure, renewable energy sources, and economic growth: Striving towards sustainable development. *Ain Shams Engineering Journal, 14*(2), 101843.

ANNEXURE

Descriptive statistics

```
Date: 04/13/25   Time: 21:05
Sample: 1990 2022
```

	MP	L_ED	GDP	L_GFCFM	L_TFP
Mean	-0.324242	9.751199	2.154949	10.35238	0.061671
Median	-0.900000	9.820867	2.600000	10.38665	0.069846
Maximum	11.60000	9.908089	5.603806	11.65872	0.137693
Minimum	-10.40000	9.443626	-5.963358	8.721765	-0.034826
Std. Dev.	4.020808	0.148766	2.443106	0.999668	0.047279
Skewness	0.190924	-0.863904	-1.203716	-0.214843	-0.436550
Kurtosis	4.598900	2.381088	4.982786	1.480164	2.236265
Jarque-Bera	3.715648	4.631514	13.37486	3.429978	1.850191
Probability	0.156012	0.098691	0.001246	0.179966	0.396494
Sum	-10.70000	321.7896	71.11330	341.6286	2.035152
Sum Sq. Dev.	517.3406	0.708203	191.0005	31.97873	0.071530
Observations	33	33	33	33	33

Unit root tests

Variables	Model	ADF		PP	
		Level	Differenced	Level	Differenced
MP	Intercept	-3.288**	-6.502*	-2.541	-8.341*
	Trend and Intercept	-4.863*	-6.467*	-3.201	-8.969*
L ED	Intercept	-2.913***	-3.976**	-2.742	-4.221*
	Trend and Intercept	0.151	-6.031*	0.563	-5.984*
GDP	Intercept	-3.581**	-5.593*	-3.606**	-7.023*
	Trend and Intercept	-3.558**	-6.012*	-3.558**	-6.998*
L GFCFM	Intercept	-0.902	-5.313*	-0.481	-4.138*
	Trend and Intercept	-1.48	-5.275*	-1.939	-5.038**
L TFP	Intercept	-1.004	-4.976*	-1.303	-4.969*
	Trend and Intercept	-1.225	-4.974*	-1.528	-4.967*

Bounds cointegration Test

Null hypothesis: No levels relationship
Number of cointegrating variables: 3
Trend type: Rest. trend (Case 4)
Sample size: 31

Test Statistic	Value
F-statistic	15.423743

Sample ...	10%		5%		1%	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
30	3.378	4.274	4.048	5.090	5.666	6.988
35	3.290	4.176	3.936	4.918	5.654	6.926
Asymptotic	2.970	3.740	3.380	4.230	4.300	5.230

* I(0) and I(1) are respectively the stationary and non-stationary bounds.

Error Correction Model

```
Dependent Variable: D(MP)
Method: ARDL
Date: 11/19/23   Time: 04:04
Sample: 1992 2022
Included observations: 31
Dependent lags: 2 (Automatic)
Automatic-lag linear regressors (2 max. lags): L  _ED GDP L  _GFCFM
      L  I_TFP
Deterministics: Restricted constant and no trend (Case 2)
Model selection method: Akaike info criterion (AIC)
Number of models evaluated: 162
Selected model: ARDL(2,2,1,2,0)
```

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COINTEQ*	-1.129050	0.191414	-5.898483	0.0000
D(MP(-1))	-0.217509	0.101011	-2.153324	0.0416
D(L _ED)	78.32110	22.82131	3.431928	0.0022
D(L _ED(-1))	79.93990	28.12921	2.841882	0.0090
D(GDP)	0.377502	0.225839	1.671554	0.1076
D(L _GFCFM)	0.782748	2.469666	0.316945	0.7540
D(L _GFCFM(-1))	-6.104385	2.865384	-2.130390	0.0436

R-squared	0.926229	Mean dependent var		-0.203226
Adjusted R-squared	0.907787	S.D. dependent var		6.880188
S.E. of regression	2.089281	Akaike info criterion		4.507196
Sum squared resid	104.7623	Schwarz criterion		4.831000
Log likelihood	-62.86154	Hannan-Quinn criter.		4.612748
F-statistic	50.22219	Durbin-Watson stat		2.017096
Prob(F-statistic)	0.000000			

*   p-values are incompatible with t-Bounds distribution.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-79.41486	NA	0.000160	5.446120	5.677408	5.521514
1	62.14594	228.3239*	8.86e-08*	-2.073932*	-0.686202*	-1.621566*
2	83.47143	27.51676	1.29e-07	-1.836866	0.707305	-1.007530

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Trace test

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.** Critical Value
None *	0.749189	93.81015	69.81889	0.0002
At most 1 *	0.491987	50.93541	47.85613	0.0250
At most 2 *	0.436530	29.94072	29.79707	0.0481
At most 3	0.289801	12.15787	15.49471	0.1495
At most 4	0.048751	1.549362	3.841465	0.2132

Trace test indicates 3 cointegrating equation(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Max-eigenvalue test

Unrestricted Cointegration Rank Test (Max-eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.** Critical Value
None *	0.749189	42.87474	33.87687	0.0033
At most 1	0.491987	20.99469	27.58434	0.2765
At most 2	0.436530	17.78285	21.13162	0.1382
At most 3	0.289801	10.60850	14.26460	0.1750
At most 4	0.048751	1.549362	3.841465	0.2132

Max-eigenvalue test indicates 1 cointegrating equation(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Cointegrating equation

```
1 Cointegrating Equation
Log-Likelihood: 115.2987

Normalized coitnegrating coefficients (standard error in parentheses)
    MP          L _ED          GDP        L _GFCFM      L _TFP
 1.000000     -13.32360     -0.231030     -2.322455     32.23573
              (9.96274)     (0.21024)     (1.54886)     (9.95792)

Adjustment coefficients (standard error in parentheses)
    D(MP)         -0.392089
                  (0.14077)
   D(L _ED)        0.007105
                  (0.00117)
    D(GDP)        -0.240615
                  (0.11616)
  D(L _GFCFM)     -0.004322
                  (0.01119)
   D(L _TFP)       0.001095
                  (0.00150)
```

Variance decomposition of MP

Variance Decomposition of MP:					
Period	S.E.	MP	L _ED	GDP	L _GFCFM	L _TFP
---	---	---	---	---	---	---
1	3.131853	100.0000	0.000000	0.000000	0.000000	0.000000
		(0.00000)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
2	4.538499	58.24582	0.498857	15.34868	11.38282	14.52382
		(11.9517)	(4.20567)	(11.6960)	(9.19012)	(8.98125)
3	4.815967	54.15762	0.712612	13.63860	12.23767	19.25350
		(12.7484)	(5.25328)	(10.7151)	(9.49609)	(10.3187)
4	4.956141	52.15887	1.327221	15.58818	11.55936	19.36636
		(13.4625)	(5.65399)	(10.8027)	(9.13133)	(10.9628)
5	5.035228	51.72779	1.463826	16.29608	11.74790	18.76440
		(13.0686)	(5.78281)	(10.4556)	(8.93186)	(10.4953)
6	5.149788	51.92340	1.414354	16.34739	11.68217	18.63268
		(13.8832)	(5.99116)	(10.5859)	(8.76508)	(10.8025)
7	5.200973	51.10701	1.542455	16.10396	11.70922	19.53735
		(13.9092)	(6.70246)	(10.8735)	(9.05869)	(11.2412)
8	5.207082	51.04885	1.601413	16.12047	11.69707	19.53219
		(14.3730)	(7.13768)	(10.9653)	(9.26100)	(11.2813)
9	5.219556	51.12291	1.601576	16.13739	11.69403	19.44409
		(14.0423)	(7.49766)	(11.0984)	(9.35742)	(11.0952)
10	5.232275	51.10833	1.593899	16.11764	11.69165	19.48847
		(14.5643)	(7.67733)	(11.1336)	(9.38620)	(11.5098)